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Living Circles Towards Green Travels: A Study on the Correlation Between Facility Layout and Travel Behavior

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* * * * *

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Beijing, November 30, 2025

Summary

Against the backdrop of global climate change, the high rate of motorization in community transportation and its associated carbon emissions are pressing urban problems that urgently need to be addressed. As the primary transition zone between walking, cycling, and driving, 15-minute living circles have the potential to promote green travel. This thesis addresses the question of how facility layout within 15-minute cycling living circles can promote green travel. Based on three types of travel behavior space, a hierarchical and phased theoretical framework is constructed for the correlation between facility layout and travel behavior. This framework includes hypotheses regarding how three travel behavior sub-goals (increasing the green travel proportion of all-type facilities, avoiding long-distance travel for single-type facilities, and promoting green travel choices for single-type facilities) are influenced by six dimensions of facility layout (attitude, density, scale, diversity, accessibility, and road condition). By three empirical studies, via mobile phone data from Tangshan and a regression-clustering methodology, the thesis reveals the influence mechanisms of facility layout on travel.

Part 1, using 634 15-minute cycling living circles, analyzes the correlation between residents' green travel levels to all types of facilities within the circle and facility layout. Regression results indicate that accessibility is generally negatively correlated, and moderate density promotes green travel. Vegetable markets and primary schools are key facilities; Learning (education) facility is driven by accessibility, enjoying (entertainment) facility relies on density, and shopping (commercial service) and caring (health) facility are driven by both. Cluster analysis shows that Near-rural Porous, Hollow-core, and Fan-shaped Radiation Living Circles have low density and poor accessibility, making them key optimization targets. Part 2 analyzes the correlation between single-category green travel and the spatial layout along the route using 31,301 residential-to-facility

OD flow clusters from eight types of facilities. Regression shows that OD distance was the dominant factor, with a significant decrease in green travel intention among residents within 1.2–2.3 kilometers. Street design variables exhibit consistent promoting effects across categories. For example, moderate street wall continuity and aspect ratios increase walking and cycling rates across multiple facility flow clusters. Cluster analysis identifies four typical street types: Multi-dimensional Promotion, Length-dominated, Leisure-enclosed, and Support-deficient Streets, providing a basis for differentiated renewal. Part 3, using 890 living circles encompassing two types of facilities, analyzes the correlation between the average travel distance for single-type facilities and the layout of that facility. Huff Models and other methods reveal that approximately half of trips to vegetable markets and over 70% of trips to supermarkets exhibit a tendency to favor more distant facilities over those located nearby. Regression analysis reveals that the largest and closest facilities within a living circle jointly determined residents' average travel distance: supermarket trips were dominated by larger, distal facilities, while vegetable markets relied on a multi-point, neighborhood-level layout. Cluster analysis identifies two types of short-trip structures: “Large nearby-small distant then short-distance convenience” living circle and “Small nearby-large distant then bypassing behavior” living circle; and two types of long-trip structures: “Flat structure then balanced distance” living circle and “Neighborhood absence then distal dependency” living circle, providing insights into optimizing facility hierarchies and alleviating long-distance travel.

Against the backdrop of global climate change and the increasing motorization of community travel, this dissertation focuses on one of China's key spatial planning innovations—the 15-minute living circle. It proposes a hierarchical cognitive framework for understanding the spatial-behavioral correlations within living circles, and develops an efficient mobile-data-based method for identifying travel behaviors. The dissertation reveals how internal facility layouts influence green travel patterns and conducts a quantitative analysis of the long-overlooked relationship between facility supply and residents' demands. It further identifies the key spatial samples and threshold conditions that promote walking and cycling, and formulates a multi-scale optimization strategy for facility layout—at the city, living-circle, and street levels—centered on critical dimensional thresholds. Overall, the dissertation provides a transferable methodological approach for identifying spatial-behavioral correlations and translating them into actionable planning strategies.

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As my doctoral journey draws to a close, I look back on years of study—from undergraduate to master's to Ph.D.—during which my passion for and understanding of urban planning have steadily deepened. The training I received at different institutions broadened my academic perspective, and ultimately, within the halls of the Tsinghua Architecture Building, these experiences converged into a coherent narrative that shaped this dissertation on Living Circle.

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CHAPTER 1 INTRODUCTION

1.1 Research background

Amid global warming, carbon reduction has become an urgent international issue that all countries must address. Urban transportation emissions account for approximately 22% of global carbon emissions, ranking second among all sectors. In many communities, facility consolidation and environmental challenges have driven a growing dependence on motorized travel even for trips whose distance less than some kilometers, resulting in considerable traffic emissions. The 15-minute cycling circle (approximately a 3km radius) not only hosts the most concentrated daily activities but also serves as a transitional space between green and non-green travel, offering significant carbon reduction potential. However, current living circle planning practices simplify scope delineation, ignore facility travel mechanism, and lacking green orientation facility layout, like facility scale, continuity. To resolve this contradiction, it is urgent to focus on the destination of travel—the facilities: exploring how different layout densities, scales, and route quality can guide green travel, and provide actionable layout optimization strategies.

1.1.1 Challenge of carbon crisis and mobility-based community travel issue

(1) Carbon Reduction as a Global Climate Strategy

In the 2030 Agenda for Sustainable Development, member countries have committed to protecting the planet from degradation and taking urgent action to address climate change. This agenda regards climate change as one of the greatest challenges of our time. Sustainable Development Goal (SDG) 13 aims to combat climate change and its impacts. The focus of SDG 13 is on integrating climate change measures into national policies and improving education, awareness, and institutional capacity for climate change mitigation, adaptation, impact reduction, and early warning systems.

As early as 2015, 196 countries signed the *Paris Agreement*, a legally binding international treaty on climate change. The agreement aims to limit the global temperature increase to well below 2°C by the end of this century. To achieve this long-term temperature goal, countries are aiming to reach the global peak of greenhouse gas

emissions as soon as possible and achieve climate neutrality by mid-century. Among these countries, China has positioned itself as a leader in climate change action. In September 2020, at the 75th session of the United Nations General Assembly, China formally proposed its "dual carbon" target: to achieve peak carbon emissions by 2030 and carbon neutrality by 2060, a strategic commitment made in the context of global calls for green recovery and China's pursuit of high-quality development.

(2) How Travel Can Contribute to Carbon Reduction: The Urgent Need for Enhanced Governance by Countries

The transportation sector is one of the significant sources of global greenhouse gas emissions^[1]. According to the IPCC's Sixth Assessment Report, transportation accounted for approximately 15% of global greenhouse gas emissions from human activities in 2019. Given the sustained high levels of emissions from the transportation sector, the international community widely recognizes it as a priority area for carbon reduction. The "Avoid–Shift–Improve (ASI)" framework, proposed by the German Technical Cooperation Agency, has become a globally accepted low-carbon travel governance approach. It emphasizes the reduction of transportation demand, the promotion of a shift to green travel modes, and the enhancement of transportation vehicle energy efficiency to achieve both structural optimization and emission reduction.

Several countries have already implemented specific action strategies. For example, Malaysia has released the *2021–2030 Low Carbon Mobility Blueprint*, with plans to build 10,000 electric vehicle charging stations by 2025 to establish a green transportation infrastructure system. However, looking at global emissions reduction pathways, the transportation sector still faces significant challenges. It is unlikely to achieve net-zero emissions by 2100 and will continue to rely on negative emissions from other sectors to offset its residual emissions. Therefore, transportation emission reduction is not only a critical task in global climate governance but also requires countries to deepen governance and continue advancing the construction of green travel systems, providing feasible paths and approaches for achieving low-carbon urban development goals^[2].

(3) Significant Non-Green Travel in Community Life

The phenomenon of non-green travel in community life is significant^[3]. Due to the rapid urbanization and car-oriented planning under modernism, newly built and redeveloped urban areas often feature the "superblock" model with single functions, massive scales, and wide roads^[4]. In developing countries, this issue is often referred to

as the “Brasilia Syndrome.” Moreover, zoning planning and facility infrastructure have not been updated in a timely manner, leading to residential and facility separation in some communities^[5]. As a result, residents are forced to travel longer distances for daily activities, and the quality of their travel environment deteriorates, prompting the passive use of public transportation or private cars^[6].

Non-green travel for community life leads to a high share of carbon emissions^[7]. On one hand, the energy consumption and carbon emissions from daily life travel account for about one-fifth to one-third of total travel emissions. According to 2010 data, energy consumption from life travel made up approximately 17.35% of total travel energy consumption, about one-fifth^[8]. Data from Jinan in 2010 indicated that non-commute energy consumption exceeded one-third^[9]. In 2007, despite slight differences across community types, daily life travel carbon emissions accounted for 33% to 66% of total emissions^[10].

On the other hand, even within a short 3 km range, motorized travel remains prevalent, resulting in high-carbon behaviors. In the United States, 65% of trips within one mile (1.6 km) are made by car ^[11]. In the Flemish region of Belgium, over 70% of trips (≤ 3 km) are made using passive transportation methods^[12].

1.1.2 Opportunity of 15-minute living circle systematization and carbon-reduction potential

(1) The Living Circle as a New Planning Level

In recent years, urban planning concepts globally have been shifting from the "block scale" to the "living circle scale," with the 15-minute living circle gradually becoming a key paradigm for guiding urban spatial structure optimization. In China, the *"Urban Residential quarter Planning and Design Standards (GB50180-2018)"*^[14] introduced the living circle for the first time, replacing the long-standing "residential quarter - community - group" model with the "15-minute-10-minute-5-minute residential quarter and residential block" concept^[15]. The scope of planning was expanded from "residential quarter planning and design" to "urban planning and the planning and design of urban residential quarters," aiming to improve accessibility through the control of facility distribution. Subsequently, in 2021, the Ministry of Commerce, in collaboration with several other departments, launched pilot projects for the construction of 15-minute convenient living circles, marking the official inclusion of the "living circle" as a

fundamental unit in China's urban planning system.

Internationally, the "15-minute city" concept, introduced in 2016, quickly became a major strategy for countries seeking to drive low-carbon urban transformation and optimize spatial organization^[16]. For example, Paris, France, implemented the living circle policy by utilizing facility co-location and restructuring public services, while real estate companies like Altarea have also promoted mixed-use development projects to meet new urban governance demands. The C40 Cities Climate Leadership Group has incorporated the "15-minute city" into its core agenda to address climate change and pandemic challenges. Many countries have now clearly included the "15-minute city" in their urban master plans and special actions, with strategies covering facility layout optimization, spatial integration, and multi-modal travel guidance, highlighting its significant role as a new level of urban spatial governance (Table 1.1).

Table 1.1 Foreign policies or reports on the 15-minute living circle

Country and City	Name	Theme/Objective
Stockholm, Sweden	1-Minute City	Construct community space facilities integrating daily functions such as public activities, delivery, and bicycle parking
Brussels, Belgium	10-Minute City	Enhance public transport accessibility of facilities
Barcelona, Spain	15 Minutes to the City Center	Build a complex functional block based on specific needs and characteristics of streets, and implement convenience improvements
Paris, France	15 Minutes to the City Center	Enhance diversity of facilities and flexibility of usage within the community; reduce car traffic and pollution
Rome and Milan, Italy	15 Projects in 15 Cities	Rome's first redevelopment intervention allocated a total of 22.5 million euros across 15 districts
Portland, USA	20-Minute Neighborhoods	Emphasize public participation, walkability, health benefits, and improve the quality of life in communities
Vancouver, Canada	15-Minute City	Center on schools and commercial districts, emphasize functional completeness within communities, and enhance connectivity within the area
Melbourne, Australia	20-Minute Neighborhoods	Full integration with planning management systems; meeting daily life needs on-site; emphasize active transportation and the convenience of neighborhood center service facilities
Sydney, Australia	30-Minute City	Improve intra-city connectivity through employment control and public transportation systems

(2) The Living Circle as the Most Intensive Space for Daily Activities

On one hand, the demand for daily travel is increasing, with lifestyle-related travel now accounting for about 50% of total trips. This shift is due to rising economic levels, improved quality of life, and diversified consumption patterns. Residents' demand for non-work-related trips to public facilities has significantly increased, including trips for shopping, cultural and entertainment activities, daily tasks, personal affairs, and other work-related purposes. In Beijing, lifestyle-related travel accounted for approximately 41.5% of total trips in 2014 and 47.3% in 2015. By 2020, this figure rose to 52.6%, excluding commuting. In Shanghai, the average number of non-work-related trips per person per day increased to 1.12 in 2014. Non-work-related trips accounted for 32% in 1995, and by 2014, this proportion had reached 52%, with the largest increase seen in daily lifestyle trips such as shopping (25.4%) and cultural and entertainment trips (9.8%) (Zhang Ping, 2019; data from Shanghai's fifth comprehensive transportation survey).

On the other hand, the living circle bears a substantial amount of travel activity, with trips within a 3-kilometer radius accounting for approximately 40% of all trips. In Tangshan, data from 2020 revealed that trips within 1 kilometer accounted for 8.23%, within 2 kilometers for 24.86%, and within 3 kilometers for 38.94%. Internationally, the 2001 National Household Travel Survey in the United States found that 50% of trips in metropolitan areas were within 3 miles (about 4.8 kilometers), and 28% were within 1 mile (about 1.6 kilometers)^[11]. In the European Union, 50% of trips were shorter than 3 kilometers^[17]. Therefore, it is clear that the proportion of daily travel within the living circle is continuously rising, and in the future, it will bear even greater daily travel demand, further cementing its central role as the most active space in the city.

(3) The Living Circle as the Conversion Space Between Green and Non-Green Travel

The travel distance and environment within the living circle influence residents' choice between green and non-green travel modes. Travel behavior exhibits a clear threshold effect with distance: the German nationwide travel survey (1976–2002) revealed that the share of walking and cycling was about 70% for trips under 1 km, dropping to approximately 35% for trips in the 1–2 km range, and falling below 5% for trips over 5 km. According to the U.S. National Household Travel Survey, the walking share in large cities was 54% for trips within 0.25 miles (≈ 0.4 km), but dropped to only 3% for trips between 1–3 miles (≈ 1.6 – 4.8 km), while car usage surged from 34% to 86%

during the same period. The 2009 NHTS survey found that for trips between 0.5 km and 3 km, the cumulative walking rate decreased from 60% to 0%. The 2016 Transportation Tomorrow Survey in Toronto showed that 2 km is a critical threshold: for trips under 2 km, the walking and cycling share (46%) exceeded that of public transit and cars (41%), but for trips over 2 km, the trend reversed.

In other words, the core 0.5–3 km segment of the living circle is the critical area where green travel modes can switch to public transport or cars. Around half of short trips in this range could be green or motorized. If facility locations and environments are optimized within this zone, increasing the green travel share by just 10 percentage points could lead to a 3–4% reduction in total motorized travel, offering a significant carbon reduction leverage effect.

1.1.3 Direction of 15-minute living circle facility optimization and green travel-effect

(1) Facilities as the Main Destination for Living Circle Travel

The foundation of living circle formation and operation lies in the fact that daily trips are primarily aimed at facilities. Compared to random "wandering" behaviors, residents' short trips are mostly directed toward specific functional facilities. According to the UK National Travel Survey (2022), around 74% of non-commute trips are to retail, dining, medical, and cultural facilities. Similarly, data from Sweden's RES 2019 study shows that nearly 75% of trips within 3 kilometers are to shopping or service facilities. To address the "work easy, live hard" problem in suburban communities caused by functional zoning and the lack of facilities, Western countries have increasingly proposed the concept of the "third place" since the 20th century^[5]. This emphasizes the key role of service facilities outside of home and work in enhancing community life quality and travel vitality. In recent years, there has been a clear trend toward the concentration of large-scale educational and commercial facilities, while local small-scale facilities are scattered and distant from residential quarters, leading to increased access difficulty and reduced service quality^[22]. Therefore, facilities, as key travel destinations, directly influence the convenience of residents' daily lives and the potential for green travel.

(2) Current Limitations in the Boundary Definition of Living Circle Planning and Insufficient Focus on Green Travel

In recent years, China has made positive strides in advancing the construction of 15-

minute living circles. Since the release of the "Urban Residential quarter Planning and Design Standards (GB50180-2018)", multi-department collaboration has been promoted, with over 100 cities nationwide launching pilot projects and more than a thousand living circle projects completed, significantly improving residents' access to services and daily convenience. This series of policies provides systematic guidance for living circle delineation, facility allocation, and land use control, laying the foundation for promoting balanced public service supply and the construction of livable communities.

Current policies and practices generally treat the 15-minute living circle as the basic planning unit for resource allocation and urban governance, dividing urban space into multiple non-overlapping, self-sufficient "square living circles" based on road and administrative boundaries. However, this approach overlooks the differences in the actual living circle ranges of different residential quarters and the reality that residents' travel paths often exceed the defined boundaries. This leads to facility mismatches due to inconsistencies between supply and use, and makes it difficult to dynamically adjust planning based on residents' real travel environments, destinations, and the usage of facilities in real time (Figure 1.1).

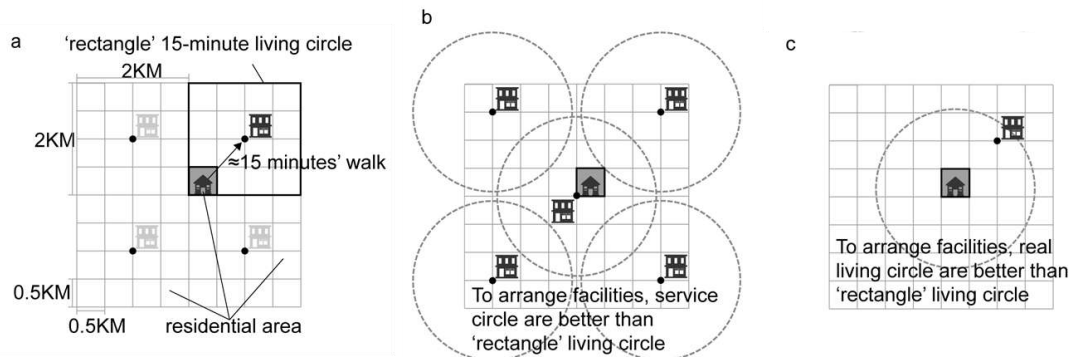


Figure 1.1 Comparison of planned 15-minute living circle facility layout and other patterns

The current standards and guidelines for living circle planning provide limited guidance on green travel planning^[23]. These standards focus on convenience indicators such as facility proximity and road density, as well as connectivity requirements like "integration with pedestrian systems and the setting of bus stops nearby." However, there is a lack of systematic consideration and regulatory requirements for urban design elements such as overall layout of facilities oriented toward green travel, suitable facility service distances for green travel, street facility density, and street continuity. This gap makes it difficult to fully support the achievement of green travel goals (Table1.2).

CHAPTER 1 INTRODUCTION

Table 1.2 Green travel-oriented planning content in Living circle Planning Standards Standard of Urban Residential quarter Planning and Design 2018 and Guidelines Technical Guidelines for Community Living circle Planning 2021

	<i>Standard of Urban Residential quarter Planning and Design 2018</i> (Ministry of Housing and Urban-Rural Development 2018)	<i>Technical Guidelines for Community Living circle Planning 2021</i> (Ministry of Natural Resources 2021) "
Accessible and dense road system	The planning and design of roads within residential quarters shall follow basic principles of safety, convenience, appropriate scale, public transport priority, and pedestrian-friendliness. Residential quarters should adopt a traffic organization model featuring "small blocks, dense road networks," with a road network density not less than 8 km/km ² ; the spacing of urban roads should not exceed 300 m and is preferably between 150 m and 250 m.	——
Comfortable and Connected Pedestrian Network	Pedestrian systems within residential quarters should be continuous, safe, compliant with accessibility requirements, and conveniently connected to public transport stations. In areas suitable for cycling, continuous non-motorized lanes should be established.	Promote green and low-carbon travel. Leveraging the 15-minute community living circle, a high-density slow-traffic network composed of urban roads, greenways, alleys, and public passages should be constructed to achieve smooth connectivity and a human-scale environment, enhance the safety and comfort of slow traffic.

CHAPTER 1 INTRODUCTION

Table 1.2 Green travel-oriented planning content in Living circle Planning Standards Standard of Urban Residential quarter Planning and Design 2018 and Guidelines Technical Guidelines for Community Living circle Planning 2021 (Continued)

	<i>Standard of Urban Residential quarter Planning and Design 2018</i> (Ministry of Housing and Urban-Rural Development 2018)	<i>Technical Guidelines for Community Living circle Planning 2021</i> (Ministry of Natural Resources 2021) "
Bus and TOD station development	Urban roads at all levels within residential quarters should highlight the characteristics and requirements of residential use, and comply with the following provisions: 1) Roads with concentrated supporting facilities on both sides should form life-oriented streets with a human scale; the building setback distance on both sides of the road should be coordinated with the street scale; 2) The red line width of branch roads should preferably be between 14 m and 20 m; 3) The road cross-section design shall meet the requirements for pedestrian and bicycle suitability, with the sidewalk width being no less than 2.5m; 4) Traffic calming measures shall be implemented on branch roads to appropriately control vehicle speeds.	Bus stops shall be configured to achieve full coverage within a 500-meter service radius, with densely populated areas preferably achieving full coverage within a 300-meter service radius.

CHAPTER 1 INTRODUCTION

Table 1.2 Green Travel-Oriented Planning Content in Living circle Planning Standards Standard of Urban Residential quarter Planning and Design 2018 and Guidelines Technical Guidelines for Community Living circle Planning 2021 (Continued)

<i>Standard of Urban Residential quarter Planning and Design 2018</i> (Ministry of Housing and Urban-Rural Development 2018) <i>Technical Guidelines for Community Living circle Planning 2021</i> (Ministry of Natural Resources 2021) "	
Facilities And layout	Regulations are provided regarding facility accessibility, scale, land area or floor area per thousand population, and co-location. For example, primary schools should be located within a 10-minute living circle; community canteens are preferably co-located with community service stations, cultural activity stations, etc. ① Element Layout ② Priority shall be given to locating elements in densely populated areas with convenient public transportation to enhance accessibility. This may include the following aspects: ③ a) Strengthen the functional correlation of service elements. Service elements with high functional correlation shall be relatively concentrated to promote the mixed-use layout of co-working spaces, lifelong education, cultural activities, fitness sports, and other service elements with commercial service land uses. Comprehensive above-ground and underground development is encouraged, advocating for the integration of medical care and elderly support, as well as the combination of cultural and sports facilities. ④ b) Guide the rational layout of service elements hierarchically. The 15-minute level should form comprehensive community service centers, covering service elements such as employment guidance, community services, and ecological leisure, leveraging community resources to cultivate distinctive functions. The 5–10 minute level service elements should be flexibly and evenly distributed, adjacent to living streets, public spaces, and greenways, ensuring convenient and friendly access for the elderly and children. ⑤ c) Link service elements via a slow-traffic network. A community living circle spatial structure of "small blocks, dense road networks" shall be established, organically connecting service elements such as employment, residence, community services, and ecological leisure through the slow-traffic network. Vital interfaces and resting facilities shall be provided, the green environment optimized, and the travel experience enhanced. In urban renewal areas, the slow-traffic network can be densified by opening internal passages, adding alleys, and providing aerial walkways and underground passages. ⑥ Shared Use ⑦ Schools, institutional ancillary facilities are encouraged to open to the community for shared use.

Although the concept of living circles was originally proposed to weaken residential boundaries, improve facility sharing efficiency, and respond to daily travel needs^[24], actual living circle planning often remains static spatial divisions, lacking a dynamic response to residents' travel behaviors and a green orientation. Building on Western experience with living circles in promoting green travel and carbon reduction, my country urgently needs to conduct locally adapted empirical research to address the dual needs of climate governance and the transition to low-carbon living^{[25][26][27]}. It is urgent to reexamine the logic of living circle facility layout from a travel perspective and explore its interactive relationship with green travel, thereby constructing a living circle spatial system that is travel-oriented and supports low-carbon goals.

1.2 Research question and significance

1.2.1 Research question

Compared with the overall scale of the city, research on green travel at the scale of living circles is still weak, and the research on the correlation between living circle facility layout and green travel still has the following deficiencies.

First, current research on the correlation between green travel and facility layout within living circles often measures travel from a city-wide or regional perspective, measuring all trips with a city-wide destination. However, the layout of facilities within living circles primarily influences trips occurring within them, particularly within a 3-kilometer radius (approximately a 15-minute bike ride). A lack of systematic analysis at this scale has led to a limited understanding of the correlation between facility layout and green travel within living circles. This 'broad' analysis only establishes a one-step correlation between facility distribution and overall green travel levels, lacking a deeper understanding of the processes involved in residents' travel behavior. In particular, the distinction between "long-distance destination selection" and "green travel mode selection" remains unclear, limiting the understanding of how the spatial pattern of facilities shapes the mechanisms of green and non-green travel.

Second, studies focusing on single-type facilities (such as a supermarket or school) often overlook the overall travel environment between the origin and destination,

focusing only on the street itself, using streets as samples, and emphasizing the correlation between street-level characteristics and the degree of green travel. This fragments the integrity of travel at a single facility, strips away the impact of distance on green travel, and fails to fully reveal the spatial and behavioral correlations between travel at a single facility. However, the travel trajectories of OD flow clusters of a single facility typically span multiple streets and are influenced by the combined effects of distance and multiple environments along the route. The underlying mechanisms of this influence remain to be explored in depth.

Third, existing research on the correlation between living area facility layout and green travel often relies on small samples, traditional questionnaires, or GPS survey data, and primarily employs linear correlation methods. The application of large-scale samples, large-scale mobile phone signaling data, and nonlinear modeling methods remains relatively limited. This limitation makes it difficult to refine thresholds for planning green travel-oriented living area facility layouts and to identify universally significant and representative living area sample types and characteristics. These methodological limitations reduce the universality and operability of the empirical results, thereby restricting their practical support for urban planning and facility renewal.

Filling these deficiencies will help to reveal in depth the spatial-behavioral mechanisms of green travel and provide more solid theoretical and methodological support for optimizing the layout of facilities in the 15-minute living circle.

Based the background and research gap, in line with the strategic goals of developing green, low-carbon cities, a 15-minute cycling living circle should be renewed from a “low green travel degree” to a “high green travel degree”, which is the goal of this thesis. The core research question of this study is: How should facilities within a 15-minute cycling living circle be planned and arranged to effectively promote residents’ adoption of green travel modes? (Figure 1.2). For each residential quarter, the proportion of green trips occurring within its 15-minute cycling range is quantitatively assessed. Residential areas exhibiting low levels of green travel require targeted spatial improvements to elevate their green-travel performance and enable their transition toward high-green-mobility living

circles. The primary lever for such improvements is the optimization of facility layout.

Accordingly, the research question is further refined as follows: Is there a measurable correlation between facility layout characteristics and the degree of green travel within a living circle, and if so, what are the specific mechanisms underlying this relationship? More specifically, do suboptimal facility distributions correspond to lower levels of green travel? Do inappropriate planning arrangements or poor spatial locations of facilities reduce residents' likelihood of choosing green travel modes?

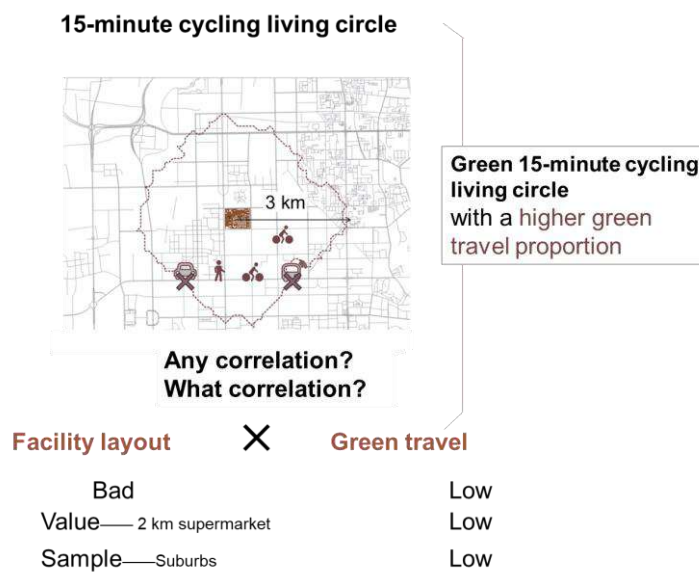


Figure 1.2 The goal green travel living circle and the question

The goal of "green travel", or “residents' green travel behaviors”, within a 15-minute bicycle living circle can be broken down and refined. If each single-type facility travel, such as high primary school travel, performs high green travel degree, all-type facility travel will perform high green travel degree. So, the goal can be divided in two perspectives: all-type and single-type. From the all-type facility travel perspective, achieving this goal equals to high green travel degree in all trips within the living circle. From the single-type facility travel perspective, achieving this goal requires focusing on two key behavioral mechanisms: (1) Whether residents engage in long-distance travel due to facility layout; (2) Once the destination is determined, whether the spatial environment influences the choice of green travel. Therefore, the general goal can be further broken down into three sub-goals: (1) improving all-type green travel degree, (2) encouraging

single-type green travel choice, and (3) avoiding single-type long-distance travel choice.

Thus, the research questions can be broken down into the following five specific questions, including three correlation questions corresponding to three sub-goals:

- 1 How should the 15-minute cycling living circle range be delineated for residential quarters?
- 2 Correspond to sub-goal ①, from the overall travel perspective, what is the relationship between facility layout and the degree of all-type green travel by residents in the 15-minute cycling living circle? How should the facilities within the living circle be arranged to allow more residents to choose green travel within the circle and have a higher proportion of green travel than other living circles?
- 3 Correspond to sub-goal ②, within the living circle, from the perspective of single facility travel, what is the correlation between residents' single-type green travel choice and the spatial facility layout when traveling to this facility? For a certain facility, what kind of location relative to the residential quarter and accordingly what kind of street characteristics along the way will help more residents choose green travel modes, conducive to that this OD flow cluster from the residential quarter to the facility has a high proportion of green travel?
- 4 Correspond to sub-goal ③, from the perspective of single facility travel, what is the relationship between residents' single-type long-distance travel and the facility layout of this facility in the living circle? How should single-type facilities be arranged within a living circle to help more residents choose nearby destinations within the circle, then have shorter average travel distances for travel within the living circle?
- 5 Can we integrate key spatial elements based on the above three correlation analysis and propose practical living circle facility layout optimization strategies to guide green travel for residents?

The detailed analysis of transferring the general goal into three sub-goals and designing three empirical studies for three questions corresponding to sub-goals are introduced in chapter 3.

1.2.2 Significance

The significance of this paper is reflected in three main aspects:

From a theoretical perspective, this paper enriches the theoretical framework for the correlation between facility layout and green travel within living areas. Current research on the correlation between green travel and facility layout within living areas primarily focuses on overall travel measurements, lacks exploration of the correlation between facility layout and green travel within specific areas, and neglects a phased analysis of residents' travel behavior. This paper focuses on the 15-minute cycling living area, a high-frequency travel zone. With a high level of green travel as the goal, this paper refines these goals by facility type and in stages. Focusing on the three sub-goals of "increasing all-type facilities green travel," "reducing long-distance destination choices for single-type facilities," and "encouraging green travel for single-type facilities," this paper systematically explores the mechanisms by which facility layout within this area influences travel variables within these three sub-goals, broadening understanding of the correlation and developing a facility planning theory for green travel.

From a practical perspective, this paper expands the perspective of OD flow clusters, analyzing the correlation between green travel levels within residential-to-facility OD flow clusters and the layout of nearby facilities. Complementing research at the living circle level, this paper explores the actual travel mode selection process from the perspective of local living circles—the spatial proximity of OD flow clusters. It establishes a facility layout indicator system for single-facility travel within OD flow clusters, explores the mechanisms by which travel distance and travel environment influence green travel for each facility type, and develops a street facility layout method for green travel. It also compares the correlations between layout and travel for eight types of facilities, such as primary schools, and summarizes the similarities and differences in the mechanisms affecting green travel across these facilities. This paper addresses the shortcomings of existing research that fragments single-facility travel, isolates the impact of distance on green travel levels, and focuses on specific street locations while ignoring the overall travel environment.

From a methodological perspective, based on a large sample size, georeferenced big data, and nonlinear modeling, it constructs a "regression + clustering" technique to reveal spatial and behavioral correlations. This approach addresses the limitations of existing research, which primarily relies on linear correlations and struggles to identify appropriate thresholds for green travel planning. Using all types of travel as an example, the methodology intuitively demonstrates how the green travel level of a living circle

varies with layout characteristics, deriving thresholds for green travel planning within a living circle. The paper then categorizes a large sample of living circles into different green travel levels, identifying living circle types with high or low green travel levels.

1.3 Concept definition

1.3.1 Residential quarter

In this paper, the boundary of a residential quarter is derived from the urban residential land represented by the 0701 code in China's third national land survey data. According to the *"Technical Regulations for the Third National Land Survey (Draft for Approval)"*, residential land is defined as "land used for various types of housing and related facilities in urban areas, excluding land for supporting commercial service facilities." Since the paper will conduct facility layout analysis, clarifying the spatial relationship between residential quarters, roads, and facilities is essential for understanding the positioning of facilities. Therefore, this paper further defines the residential quarter as **"a contiguous residential land area within arterial roads, primarily consisting of residential buildings"**.

The residential quarter in this paper has the following characteristics:

First, it does not extend across major urban roads, and it is enclosed by residential land within blocks bounded by arterial roads. The arterial roads correspond to the main roads, secondary roads, and access roads in the OpenStreetMap data, as well as urban road land in the third national land survey data of China.

Second, it is primarily residential, with few other life service facilities or functions, except for accessory roads, parking lots, and ground-floor commercial areas attached to residential buildings. According to the technical regulations' classification and definition, residential quarters do not include land for education, healthcare, culture, sports, parks, and green spaces (classified under "Public Administration and Public Services Land" 08), nor do they contain retail commercial, dining, and entertainment land classified as "Commercial Service Land" 05. Furthermore, the "residential quarter and sub-community-level supporting service facilities" fall under "service facilities land (R12, R22, R32)" for community-level services such as daycare, culture, sports, commercial services, health, and elderly care, as defined in the *"Urban Land Classification and Planning Standards"*. In contrast, residential quarters correspond to "residential land (R11,

R21, R31)," which includes residential buildings, access roads, parking lots, and small recreational areas. Based on the empirical analysis to be presented, since facilities such as ground-floor commercial areas overlap with residential projections, it is difficult to separate these from residential buildings using boundaries, so residential quarters are considered to include a small amount of commercial space. Therefore, the residential quarter is primarily composed of residential buildings and contains very few facility buildings (Figure 1.3).

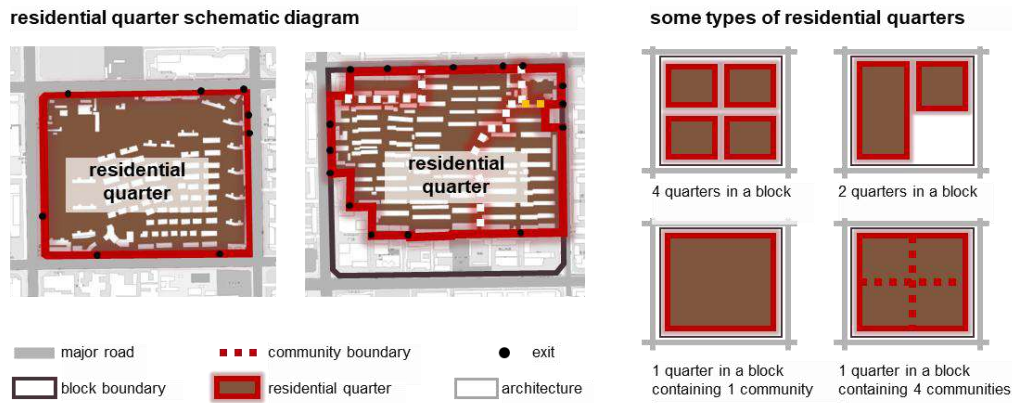


Figure 1.3 Residential quarter diagram

1.3.2 15-minute cycling living circle

In this paper, the "15-minute cycling living circle" is defined as **“the range reachable by bicycle within 15 minutes from the centroid of the residential quarter”**, a scope drawn by Gaode API when the mode is set by cycling, and not drawn by phone data. The specific method is introduced in Chapter 3.1. Unless specifically stated, it will be referred to as the "15-minute cycling circle," while the "15-minute walking living circle" is defined as the area reachable by walking within 15 minutes from the residential centroid, and will be referred to as the "15-minute walking circle." For the same residential quarter, both the 15-minute walking circle and the 15-minute cycling circle start from the centroid of the residential area. The difference is that the 15-minute cycling circle is larger than the 15-minute walking circle.

In the following sections, the 15-minute cycling circle is used to analyze the facility layout and green travel. The green travel rate within the 15-minute cycling circle is measured, and areas with a higher green travel rate can be referred to as “high green travel rate living circles.”

1.3.3 Green travel

In this paper, "green travel" is defined as slow mode including "walking and cycling", while "non-green travel" refers to "motorized transportation" including "bus and car". In the empirical part of this paper, 4 modes of trip of phone data are identified: walking, cycling, bus and car, the detail of identification is introduced in 3.4.3.2.

The concept of "green travel" originated from the need to address traffic-related carbon emissions and the urban transition toward sustainability. In international academic and policy contexts, it often aligns with terms like "sustainable transportation" or "active travel." "Sustainable transportation" emphasizes the environmental, economic, and social sustainability of transportation systems, advocating for low-carbon travel alternatives to improve urban resilience^{[28][29]}. "Active travel," on the other hand, focuses on walking and cycling as forms of physical activity, highlighting their positive effects on health and the environment^[30].

This study uses walking and cycling as the core forms of green travel, primarily for two reasons: First, walking and cycling are a common trend in urban sustainable development. Developed countries have generally experienced a three-phase transition: "walking/cycling — motorization — green return." For example, Copenhagen transitioned from a "bicycle city" to an "automobile-dominated city" and then back to a "livable city" through soft mobility^[31]. Similarly, the UK entered a pedestrian-dominated urban renewal phase after the 1970s^[32]. Second, the 15-minute city concept emphasizes walking and cycling as the primary means of transportation, with the goal of meeting daily needs within 15 minutes using non-motorized travel. In Paris's 15-minute city practice, the government implemented policies such as the "2021–2026 Bicycle Plan" to build city-level cycling networks, reduce car parking spaces, and expand non-motorized infrastructure to transform Paris into a "100% bikeable city"^[31].

Therefore, based on the international concept system of green travel, the core principles of the 15-minute city theory, and urban practice experience, this paper treats walking and cycling as the core types of green travel. Subsequent analyses of travel behavior and facility layout optimization will be conducted based on this framework. In the general travel study, the level of green travel for residential quarters is described by the proportion of walking and cycling in all travel modes within the 15-minute cycling living circle.

1.3.4 Service facility

To describe the facility layout within the 15-minute living circle and categorize travel purposes, this paper constructs a service facility classification system. "Service facility" will be referred to as the "Facility". The major categories of facilities are based on Professor Moreno's six dimensions of the "15-Minute City" framework in his book^[34], **which include 5 types of non-work travel purposes: Learning, Caring, Shopping, Enjoying, and Traveling. Under this framework, the paper incorporates 16 subcategories of facilities.** These subcategories are classified according to the "*Urban Residential quarter Planning and Design Standards (2018)*" and the "*Urban Public Service Facility Planning Standards (Draft for Comments)*." **The relationship between the 5 major categories and 16 subcategories is shown in the Table 1.3 and the basis is in Figure E.3.**

This facility system has the following characteristics: First, it comprehensively covers the types of daily-use facilities listed in the 2018 standards, including public administration and public services, commercial services, and transportation facilities, encompassing both market-oriented and public functions.

Second, it includes service facilities at different levels, such as municipal and district-level facilities, rather than being limited to community-level ones. This reflects the fact that the service range of the 15-minute cycling living circle, which covers nearly 3 kilometers, can accommodate multi-level facility layouts. For example, municipal-level facilities like cultural centers are also included in the study. Third, within each subcategory, the facilities have a high degree of functional consistency. The travel purposes for residents visiting any facility within a given subcategory are essentially similar. For example, in the case of the "courier and postal service points," the "courier" and "postal service points" are combined as a single category because they both serve the residents' parcel pickup and delivery needs. This classification system provides foundational support for the subsequent analysis of the green travel mechanism.

CHAPTER 1 INTRODUCTION

Table 1.3 Facility types

Source: Summarized by the author

16 Types of Facilities			
Category – Learning/ Education			
Type	1 Primary School	2 Middle school	3 Kindergarten
Subtype	---	--	--
Category – Caring/ Health			
Type	4 Health Service Center	5 Pharmacy	6 Fitness Center
Subtype	Clinic, Community Service Community Service Station	Hospital, Health Center, Health --	Sports Center, Stadium, Sports Training, Sports and Leisure Services
Category – Shopping/ Commercial service			
Type	7 Supermarket	8 Vegetable Market_Fresh Market	9 Community Commercial Outlet/ Department stores
Subtype	Supermarket, Department Store, Supermarket, Market, Specialty Commercial Street	Open-air Market, Fruit Vendor/Agricultural and Sideline Products Market, Fruit Market, Vegetable Market, Aquatic and Seafood Market	Computer Store, Stationery Store, Jewelry Store, Barber Shop, Car Dealership, Laundry Service, etc.
Type	10 Dining	11 Express & Postal Outlet	
Subtype	Restaurant, Café, Fast Food, Bar, Pub, Bakery, Outdoor Store, Beverage Shop, Food Court	Express Delivery, Postal Business Outlet	
Category – Enjoying/ Entertainment			
Type	12 Park & Square Attraction	13 Cultural Activity Center	14 Community Service Center
Subtype	Monument, Fountain, Viewpoint, Playground, Memorial Hall, Picnic Spot, Attraction, Shelter, Historic Site, Children's Play Area, Park	Museum, Art Center, Library, Theater, Cinema, Science Museum, Archives, Cultural Palace	Community Center, Registration Office, Social Services/Sub-district Office, Community Council, Community Service Center, Human & Social Services
Category – Traveling/ Transportation			
Type	15 Bus Stop	16 Parking Lot	
Subtype	Bus	Surface, roadside, underground	

1.4 Case study city and samples

1.4.1 Case of Tangshan

Tangshan is a prefecture-level city in Hebei Province, located at a key node of the Beijing-Tianjin-Hebei metropolitan area. It is an industrial city undergoing urban renewal and transformation. The built-up area of Tangshan is the focus of this study, with a population of approximately 3.39 million and an area of around 1361 square kilometers as of 2020, which is the scope in three correlation studies in this thesis (Figure 1.4).



Figure 1.4 Tangshan's urban landscape and built-up area location

(1) Tangshan's Diverse Residential Types: A Reference for Cities at Different Stages of Development

Tangshan has produced diverse residential quarters in the process of modern evolution (Figure 1.5). With the evolution of urbanization and industrial transformation, Tangshan has formed a complete residential evolution trajectory, starting from modernist street areas, experiencing the influence of neighborhood units and zoning planning, to the construction of modern residential quarters after the earthquake^{[35][36][37][38]}, as well as the transformation of small blocks^{[39][40]}, and then to the renewal of residential quarters guided by living circles. At present, Tangshan covers five types of residential quarters: affordable housing residential quarters, traditional neighborhood style residential quarters such as hutongs and alleys, village reform residential quarters such as urban villages, unit based residential quarters, and commercial housing residential quarters (Figure 1.6). It almost covers all types of residential quarters since the reform and opening up, and has strong universality. Each type of residential quarter has differences in spatial form, service facility, development background, especially in block scale, degree of functional mix, and level of facility supply, providing rich samples for analyzing the correlation between facility layout and green travel^[41].

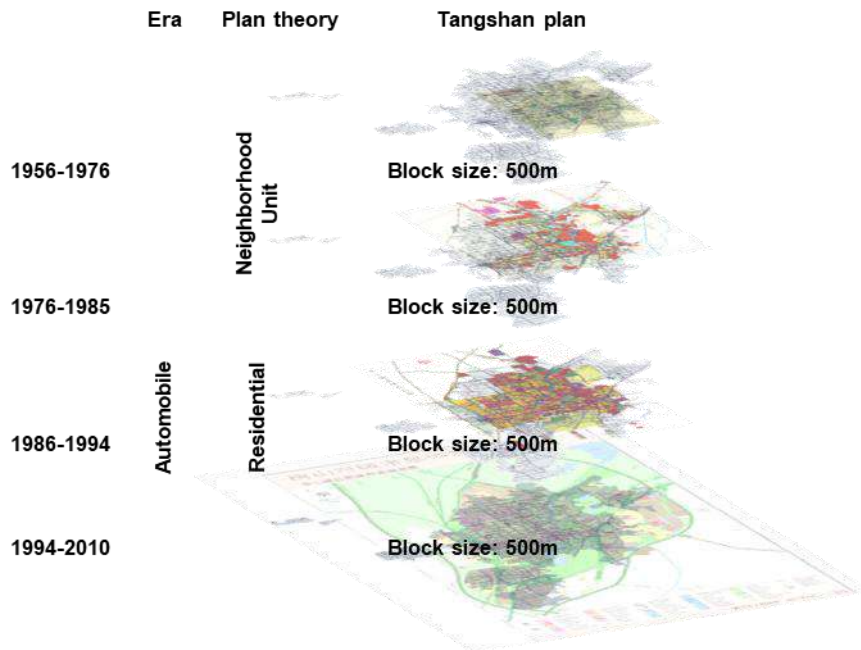


Figure 1.5 Tangshan planning concept evolution, historical planning map and typical residential quarters

Type	Traditional neighborhood communities (such as hutongs and lanes)	Unit-based community	Village-to-residential community (such as urban villages)	Commercial housing community	Affordable housing community
Spatial form	Low building density, low-rise zigzag blocks, high greening rate.	North-south oriented slab blocks, mostly low- and mid-rise.	Predominantly mid- to high-rise buildings, characterized by high floor area ratios.	Dominated by mid- to high-rise apartments, with car-oriented road networks and sufficient parking supply.	High-density, low-greening environments with modest design due to cost constraints.
Service facilities	Relatively complete internal services; road network curved and fine-grained	Facilities comprehensively provided by work units, including kindergartens, clinics, canteens, small shops, and sports amenities.	Limited internal services, highly dependent on external supply.	Oriented towards residential use, with only partial provision of commercial and public services.	Limited supporting services and relatively basic infrastructure.
Development background	Concentrated mainly on the northern bank of the Douhe River, representing the early urban fabric.	Built since the early 1980s by large state-owned enterprises such as China Railway, Tangshan Steel, and transportation companies.	Initiated through the "ping gai lou" and village redevelopment projects since 2005, scattered across the city.	Rapidly expanded since the 1990s with the commercialization of housing, becoming the most numerous and widely distributed type.	Launched as a government-led housing program since 2005, with a small share in the total housing stock.
Graphics					

Figure 1.6 Tangshan residential quarter types based on the community classification method adopted in the 2023 Urban Health Check of Tangshan

(2) Tangshan as a Pilot City for the 15-Minute Living Circle: Pioneering Facility

Update Practices

In 2021, Tangshan was selected as one of the first cities to implement the 15-minute living circle pilot program^[42]. Leveraging the "*Tangshan Central Urban Area Convenient Living Circle Construction Plan (2021-2035)*" prepared by the Tangshan Urban Planning and Design Institute, the city established a detailed set of facility configuration principles and layout strategies, based on the division of three living circles. This systematic division and facility configuration system provides a point of entry, institutional support, and practical foundation for this study, and facilitates the translation of research findings into actionable planning recommendations.

Based on block length, road systems, and administrative boundaries, Tangshan's built-up area was divided into 48 15-minute living circles, 290 10-minute living circles, and 4907 5-minute living circles to ensure that residents can easily access various public service facilities (Figure1.7). Block length is the most crucial division criterion, ensuring that facilities are accessible within the designated walking time. For example, the 15-minute living circle's block length was defined as a 2x2 km area, allowing residents to reach facilities within a 0 to 1.4 km walking radius, or about 15 minutes on foot (Figure1.8).

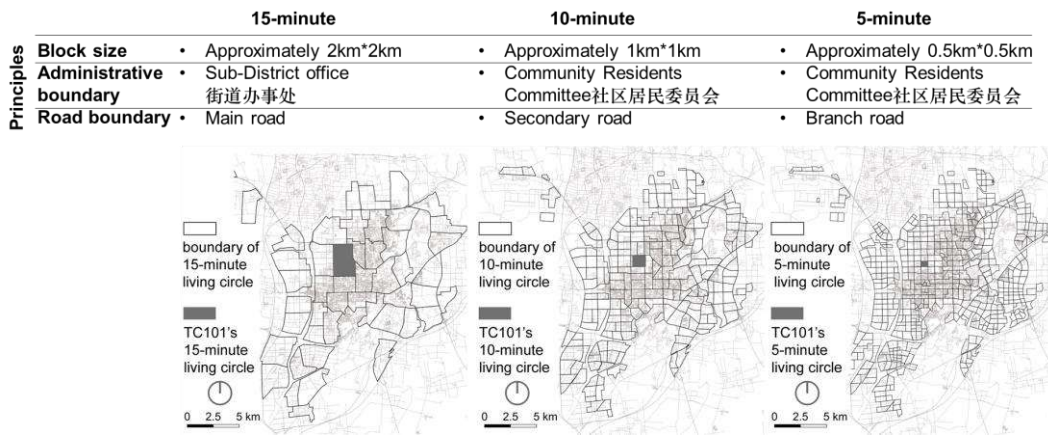


Figure 1.7 Division of 15-minute, 10-minute, and 5-minute living circles in the "Tangshan Central Urban Area Convenient Living Circle Special Plan (2021-2035)."

(Source: Author's Revised Drawing)

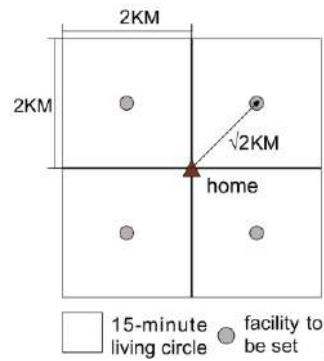


Figure 1.8 The reason for 15-minute living circle block length of 2×2 kilometers

Ensuring that the farthest resident (1.4 km) can reach facilities within 15 minutes of walking.

The principles of facility layout vary by category, mainly involving service radius, thousand person quota, and building area. Taking the vegetable market as an example, it should be located in a 10 minute living circle with a service radius of 500 meters. The number of vegetable markets in each 10 minute living circle should be determined based on the population within the circle and the "50-100 square meters per thousand people configuration", but at least one. At the pilot level of 5-minute living circle, based on the evaluation of the current status of facilities, the content of facility updates will be determined and a construction plan will be formulated (Figure1.9). It can be seen that the planning of Tangshan's living circle focuses on facilities and attempts to achieve the goal of green convenience through "facility renewal" (APPENDIX A).

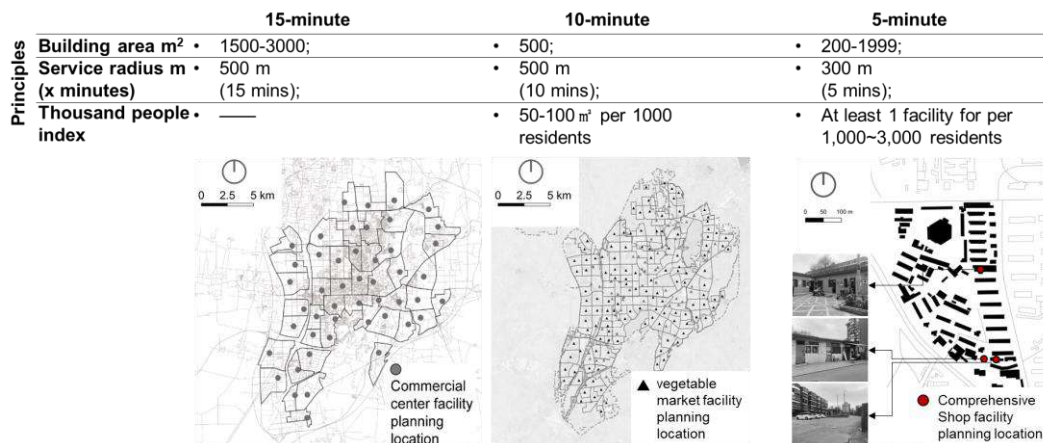


Figure 1.9 Facility layout in the "Tangshan Central Urban Area 2021-2035 Convenient Living Circle Special Plan."

(Source: Author's Redrawing)

Choosing Tangshan as a case study not only facilitates the exploration of facility layout optimization under the guidance of green travel but also supports Tangshan in its future urban renewal and green travel policy formulation, responding to the city's pressing need for a green transformation and improved travel convenience. Additionally, Tangshan's diverse residential quarters and forward-looking policies offer valuable lessons and a reference model for other cities at different stages of development, showcasing a high degree of external applicability.

1.4.2 Living circle sample and OD sample

The research samples in this study are divided into two categories: residential living circle samples (represented by ©) and residential-facility OD flow cluster samples (represented by ※). For the full travel category study, 860 residential living circles are used as samples, while the single-category travel study primarily uses over 10,000 residential-facility OD flow cluster samples within these residential living circles (Figure 1.10).

For the full travel study, living circles are used as samples and statistical units to analyze travel and layout characteristics and explore their correlation. For the single-category study, research will be conducted at two levels — the living circle level and the OD flow cluster level. In addition to the living circle as the statistical unit, the OD flow cluster will be introduced as a sample and statistical unit, as this level is more closely related to residents' travel patterns, capturing the features of travel, green travel choices, and the micro-environment of the travel process. The two levels will be analyzed together, using indicators such as travel distance, travel ratio, travel probability, layout density, and layout distance, to comprehensively reveal the relationship between travel and facility layout.

The travel behavior of residents is essentially a process starting from the residential quarter, passing through streets, and reaching destination facilities. The connections formed by residents traveling from their living areas to facilities can be referred to as OD connections. When multiple residents from the same residential quarter travel to the same facility, the collection of these connections forms an OD flow cluster. The detailed description and method of OD flow cluster are introduced in Figure 6.2. These OD flow clusters share several common attributes, such as residential attributes, distance, and facility characteristics. Thus, this study defines a flow cluster as a line connecting the

centroid of a specific residential quarter to the centroid of a specific facility, with each residential quarter having a unique OD flow cluster to each facility.

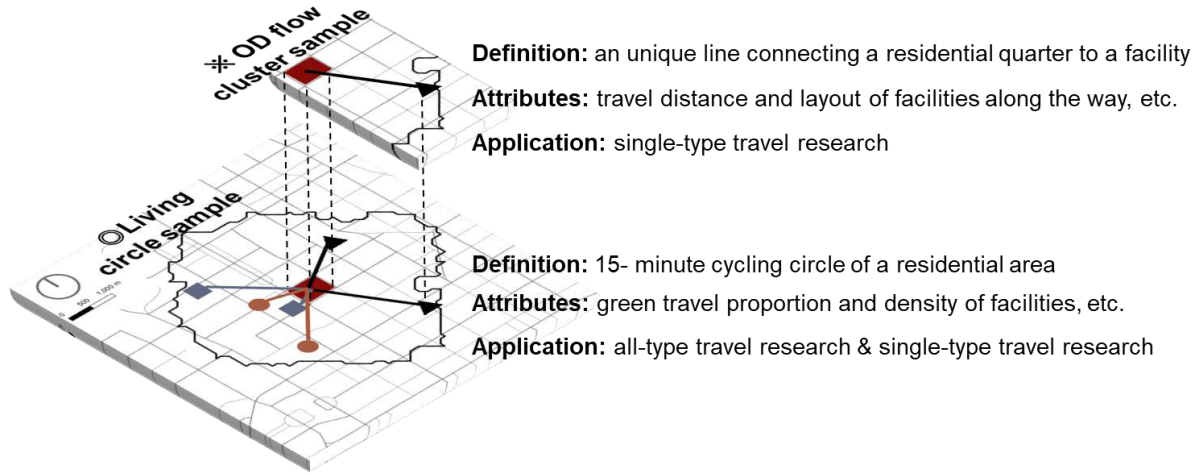


Figure 1.10 Two types of samples

1.5 Thesis structure

This thesis is divided into eight chapters, with the following structure (Figure1.11) :

Chapter 1: Introduction

This chapter outlines the value of the research topic and discusses its background and significance in the context of major practical issues, as well as theoretical and practical frontiers. It introduces the case study city and research samples selected for this study, and clarifies the research approach and technical route.

Chapter 2: Literature Review

This chapter reviews research on facility layout in living circles, green travel in living circles, and the correlation between facility layout and green travel. It summarizes previous findings and draws insights to inform the current study.

Chapter 3: Cognitive Framework and Research Design

This chapter first introduces the method for defining the 15-minute cycling living circle and applies it to residential quarters in Tangshan, providing the main research scope for the three subsequent correlation studies. Then his chapter focuses on the theoretical framework and research design for studying the relationship between the 15-minute cycling living circle's facility layout and green travel. The second and third steps of Four-stage traffic demand model—travel distribution and mode choice—serve as inspiration

for the two-stage framework of "destination choice–green travel mode choice" in single-category travel. Based on the two perspectives ‘all-type and single-type’, and two processes ‘travel destination choice and green travel mode choice’, the general goal ‘green travel’ is broken into three sub-goals. These theories, Planned Behavior, the Huff Model, and the Living Circle, the 15-Minute City, 5D Theory, and Walkable City Theory, inspire the development of six interaction dimensions of facility layout, constructing the assumptions for travel behaviors in three sub-goals, then a three correlation analysis framework for research design.

Chapters 4 to 6: Empirical Studies

Chapters 4, 5, and 6 present empirical studies based on the correlation analysis framework developed in Chapter 3. The studies analyze the correlation between full-category green travel choices, single-category facility green travel choices, single-category long-distance travel choices, and their respective facility layout factors. **Chapter 4** measures the correlation between the full-category green travel level in 634 residential living circles and facility layout characteristics. Key facilities, important layout features, and ideal layout planning values for promoting green travel are identified, and the living circles are categorized. **Chapter 5** focuses on eight facility types such as supermarkets and markets, measuring the green travel proportion of over 30,000 OD flow clusters and the street condition features. Regression analysis identifies key layout features and street designs conducive to green travel, followed by street categorization. **Chapter 6** examines the impact of facility supply characteristics on long-distance travel choice and measures the average travel distance in living circles, identifying the facility layout features corresponding to long-distance travel. The living circle travel patterns are categorized.

Chapter 7 and 8: Findings, strategies and conclusions

These two chapters provides recommendations on how to optimize the layout of facilities within the 15-minute living circle to encourage green travel. Based on the findings from the correlation studies, and drawing on international experience, the **Chapter 7** offers suggestions for updating living circles facility layout with a green travel-oriented approach. The **Chapter 8** concludes by summarizing the main findings and conclusions of the thesis, highlighting its innovative aspects, discussing the limitations of the study, and suggesting directions for future research.

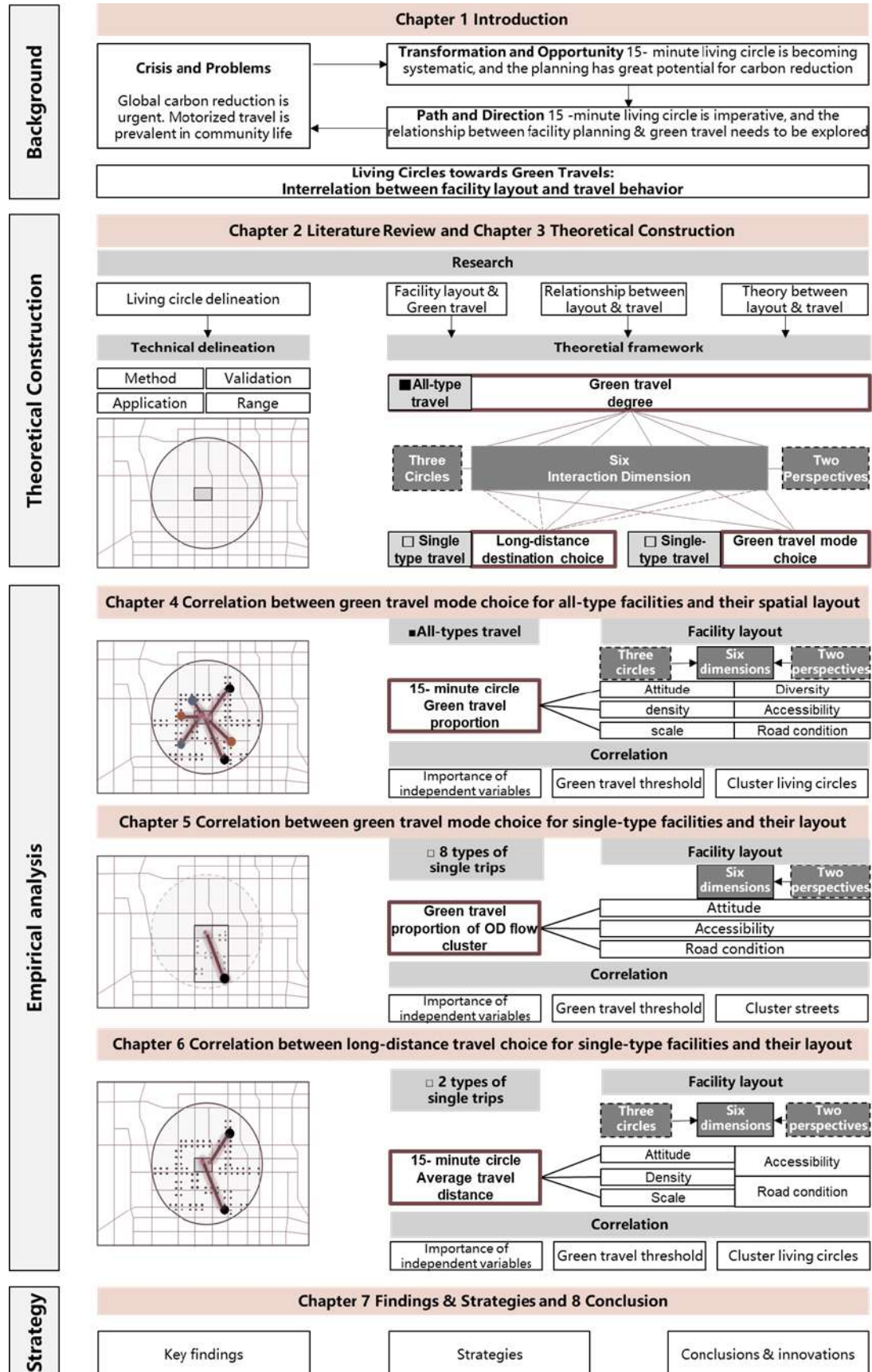


Figure 1.11 Thesis structure

CHAPTER 2 LITERATURE REVIEW

2.1 Research of living circle facility layout

2.1.1 Planning by location, scale, radius, and form

(1) Origins and Development of the Concept of Living Circles

- International origin of living circle

The concept of living circles originated in Japan. In 1965, Japan proposed the concept of the broad-area living circle at the regional level to optimize the distribution of infrastructure and public services and promote balanced regional development. In 1969, the "Third National Comprehensive Development Plan" introduced a "settlement concept," dividing Japan's living areas into four levels: living circles, settlement circles, neighborhood circles, and block circles. The settlement circle, similar to the 15-minute living circle in China, refers to the spatial scope of daily commuting (to work or school), shopping, leisure, and medical activities centered around the family.

In the 1980s, South Korea introduced the regional living circle development strategy in the "Second National Land Comprehensive Development Plan" to expand employment opportunities, improve service facilities, and enhance national welfare. The plan divided the country into 28 living circles, including five major city living circles, 17 regional city living circles, and six rural living circles. Influenced by Japan's concept, South Korea incorporated the idea of living circles into residential planning, matching residential quarters with large, medium, and small living circles, emphasizing the relationship between circle scale and population.

In 1979, Taiwan also adopted the concept of the living circle in its comprehensive development plan to implement hierarchical control of urban space. The key elements of defining a living circle include administrative boundaries, lifestyle, planning layout, transportation conditions, and information technology. Its core is to define land scale, transportation networks, and infrastructure planning based on people's activity needs, aiming to promote regional balanced development and improve the quality of life.

Paris is actively promoting the "15-Minute City" concept: residents should be able to walk or cycle within 15 minutes to reach workplaces, schools, shops, entertainment, cultural, and leisure venues. Achieving this vision requires large-scale decentralization,

reducing motorized traffic, adding bike lanes, creating local shops, and enhancing the use of public spaces. In essence, the "15-Minute City" seeks to fill urban space with more people and functions, rather than cars. It also advocates for a return to more localized, slower lifestyles, allowing longer commuting times to be spent building richer neighborhood relationships. This concept was included in the Paris municipal strategy "Paris En Commun" as a core platform during Mayor Hidalgo's 2020 re-election campaign to address climate change challenges through community activation.

Following the pandemic, the Italian government has also adopted this concept. Similar to the "Paris En Commun" strategy, "Milano 2020" emphasizes rediscovering the scale of communities (within 15 minutes walking distance) to ensure all residents can access nearly all services within walking distance. The concept aims to strengthen public services, focus on local communities, balance regional differences, and reduce cross-district travel. The city government is working with the Lombardy region, focusing on high-density, aging neighborhoods to establish local medical services and transform a series of public squares as another point of focus.

Melbourne proposed nine principles in its "2017-2050 Melbourne Plan," one of which promotes local life through the "20-Minute Community" model. This model defines the community as one where people can meet most daily needs within 20 minutes by walking, cycling, or using local public transport. The goal is to improve health, reduce travel costs, alleviate traffic congestion, and reduce vehicle emissions. These communities will offer a wide range of urban and social services, aiming to enhance prosperity, health, social inclusion, belonging, participation, choice, adaptability, and employment opportunities. Notably, the "20-Minute Community" includes 17 essential urban and social functions within its jurisdiction. The "Community Activity Center" (NAC) is a key feature, providing entertainment, retail, services, and education, and will also serve as a workplace, fostering social interaction and community engagement. This model doesn't specify the actual community scale but implicitly defines it by the distance people can walk, cycle, or use local public transport in 20 minutes.

The U.S. Portland Plan (2012) introduced the concept of "Complete Communities (CN)," emphasizing a community where residents can safely and conveniently access the goods and services needed for daily life. These include diverse housing options, grocery stores, public schools, open spaces, entertainment facilities, affordable active transportation options, and municipal facilities. To apply the "Complete Communities"

model, the U.S. has developed a 20-Minute Community Index to assess accessibility to service facilities. A community scoring 70 or more out of 100 is considered relatively complete. The goal is for 90% of residents to meet all their non-work needs within 20 minutes by walking or cycling.

● Development of Living Circles in China

The origin of the "residential circle" theory in China can be traced back to the "Complete Communities" concept proposed by Wu Liangyong. He believed that communities should be integrated spaces with multiple functions. Influenced by Patrick Geddes' regionalism, Perry's neighborhood unit planning concept, and Henry Stern Churchill's human-centered approach, Wu Liangyong proposed that the starting point for community planning and construction should be the practical interests of grassroots residents, encompassing not only housing issues but also services, security, health, education, internal and external transportation, entertainment, and cultural parks, thus defining the "Complete Communities" concept^[44].

In recent years, the concept of the "15-Minute Living Circle" (also known as "15-Minute Community Living Circle") has gained widespread attention. The concept was first implemented in Shanghai^[45], and has since influenced the planning efforts of major cities like Guangzhou, Jinan, Changsha, and Xiamen^[46], as well as the development of hot construction areas like Xiong'an New Area^[47]. It was also incorporated into the 2018 "Urban Residential quarter Planning and Design Standards", becoming a key part of detailed national land space planning practices^[48].

(2) Facility Layout in the Living Circle Theory

As a core element in residential living circle design, facility layout lays the spatial foundation for the realization of concepts such as the "15-Minute Living Circle" by promoting compact, walkable, and functionally complete urban forms (Figure 2.1).

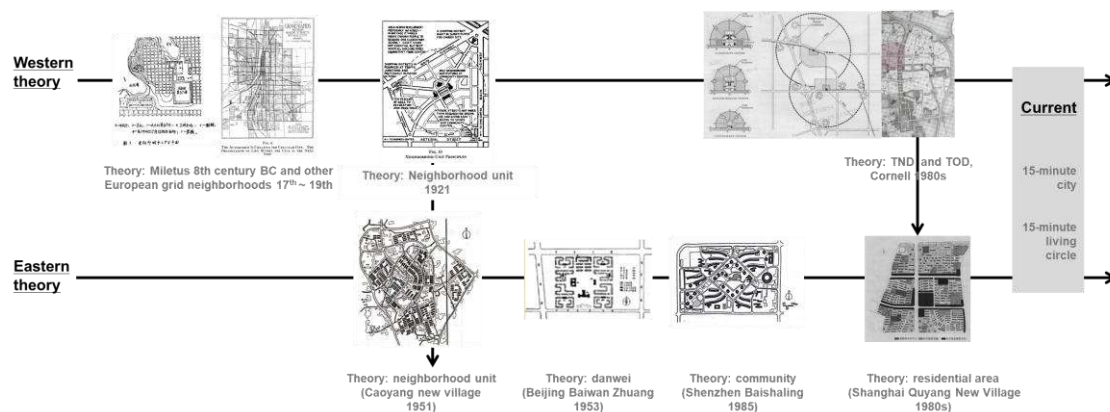


Figure 2.1 Evolution and dissemination of living circle theory and facility layout

source: drawn by author

In the West, the tradition of facility layout can be traced back to the 8th century BC Greek and Roman city models, where service facilities were densely distributed along main streets and squares, emphasizing walkability^[49]. This layout style continued into European cities of the 17th to 19th centuries (e.g., Turin, Italy), where small-scale blocks and diversified facility layouts became key features of livable cities. In the early 20th century, influenced by the rise of automobile traffic, the "neighborhood unit" planning concept emerged, emphasizing the separation of traffic and the integration of walkability through blocks surrounded by main streets with public facilities inside^{[50][51]}. Since the 1980s, in response to suburban sprawl, New Urbanism (TND, TOD) inherited and emphasized corridor connections, small-scale blocks, and mixed-use layouts^{[52][53]} (see Figure 5).

In the East, Chinese urban space has also undergone an evolution from traditional Li-fang and Li-long block systems to the unit and residential district-residential quarter-group system influenced by neighborhood units, Soviet neighborhood units, TOD, and TND^[54]. In the mid-to-late 20th century, projects like the Caoyang New Village in Shanghai, Million Village in Beijing, Baishaling in Shenzhen, and Quyang New Village reflected explorations of multi-layered facility layouts and improved accessibility^{[55][56][57][58]}.

Based on the development background of both the East and the West, the evolution of facility layout reflects four key principles: (1) Type: prioritizing the allocation of community centers, commercial spaces, and basic educational facilities; (2) Location: Facilities are arranged in the center of the block or near major roads and traffic nodes; (3) Scale and service radius: Reasonably define the service scope based on the population density and spatial scale of the planning unit, and meet the 15 minute accessibility standard (Figure 2.2); (4) Form: Adopting a point like gathering or corridor layout to enhance spatial coherence and convenience for residents. These principles provide an important framework for understanding the spatial logic of facility layout within a 15 minute living circle, and lay a theoretical foundation for the subsequent analysis of block size and facility layout characteristics.

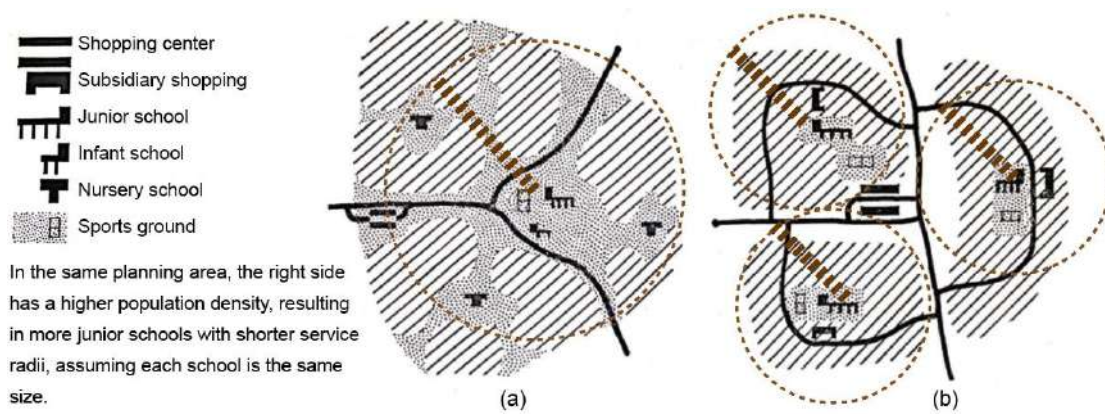


Figure 2.2 Facility service radius determined by regional area, population density, and facility scale

Source: adapted from^[51]

2.1.2 Measuring by density and nearest neighbor

(1) Living Circle

Facility layout in the living circle refers to the spatial distribution of facilities around a specific residential quarter. Existing studies typically describe this distribution using indicators such as density, accessibility, equity, quantity, nearest neighbor index, and the spatial location coefficient^[59]. Zhu Wei analyzed the impact of the quantity of facilities such as parks and supermarkets on the frequency of family daily trips, constructing a spatial behavior mapping model^[60]. Staricco, L. compared the number of facilities within the 5-minute, 10-minute, and 15-minute walking circles of all residential quarters in Turin, Italy, revealing the spatial heterogeneity of facility layouts^[61]. Zhao Pengjun determined the range of living circles in Beijing and the accessibility of service facilities, finding that the accessibility level of cultural and leisure facilities had a low impact on the living circle's range^[62]. Zuo Jin et al. analyzed the current state of service facility layout in Hedong District, Tianjin, evaluated the current facility layout based on the degree of facility arrangement, the number of facilities residents can access within a 15-minute living circle, and the coverage of various facilities^[64]. Based on these evaluations, they optimized the facility layout by using steps such as determining potential sites, minimizing facility models, and applying the minimization impedance model. The optimization results indicated the “least construction volume, shortest travel distance, and maximum facility coverage.”

(2) Street Layout

Many facilities in living circles are distributed along streets^[65]. Some studies have focused on the street facility layout in living circles and proposed indicator systems. Long Ying et al. measured the functional mix, functional density, intersection density, and distance from the city center for over 700,000 streets in 287 cities across China, revealing the polarization phenomenon of street facility layouts^[66]. Shuyang Zhang measured the wall continuity and residential building density of streets within the second ring of Beijing^[67]. The street width-to-height ratio and integration were also used to describe street facility layouts.

2.1.3 Visualizing by area and network kernel density

(1) Living Circle

In contrast to quantitative analysis, which often focuses on individual types of facilities, spatial analysis allows for the overall layout analysis of facilities within living circles. Many studies in spatial analysis are based on kernel density. Zhang Ping and Song Jixiang summarized the layout of public facilities in large suburban communities in Shanghai, identifying the "corridor-type" or "network-type" open layouts along community roads, and categorized facility layouts into three tendencies: "clustered," "dispersed," and "clustered + dispersed"^[68]. Li Heng et al. demonstrated the clustering distribution of service facility points, revealing an overall pattern of gradient density decreasing from the urban core to the outskirts. Other studies on facility clustering include Zhang Jiaqi, who used methods such as kernel density analysis, overlay analysis, standard deviation ellipses, and spatial correlation analysis to study the spatial distribution of life service industries in Zhengzhou. Wang Lucang utilized multi-source data, including POI, and applied spatial autocorrelation and coordination models to explore the configuration of public service facilities in Lanzhou from the perspectives of "land suitability" and "human suitability."

(2) Street Layout

As many urban facilities are distributed along street networks, such as restaurants, banks, and traffic accidents, both domestic and international researchers have proposed network-based spatial point pattern analysis methods. These methods use shortest-path distances instead of Euclidean distances to measure the spatial distribution of event points, overcoming the limitations of traditional analysis methods and applying them across different fields. Okaba and Yamada extended the planar K-function method into network

space, proposing the Network K-function method and developed the SANET tool for network-based spatial point pattern analysis. Garrocho-Rangel et al. used the Network K-function method to analyze the aggregation pattern, scale, and intensity of economic units within cities. Zeng Xuan et al. applied network point pattern analysis to study the spatial distribution of restaurants, confirming a significant clustering relationship with bus stations rather than residential quarters. Yu Wenhao et al. used network kernel density estimation to analyze the distribution characteristics of urban service facility hotspots.

In terms of morphology, Wang Chenghui and Hu Mingxing identified four main building types based on openness, building volume, and spatial composition: Type A - medium and large-scale facilities on independent land; Type B - small-scale independent facilities; Type C - ground-floor facilities attached to residential buildings; Type D - closed layout, and proposed 17 derivative classifications^[69].

2.2 Research of living circle green travel

2.2.1 Green travel-oriented planning theory and practice

(1) Theory

● Classic Walking Theory

Simmons et al. (1988) and colleagues first proposed a socio-ecological model to promote physical activity. The model identified key behavioral factors, including behavior outcomes, barriers, perceived self-efficacy, social influences, and physical environment, alongside policy impacts. The model explored physical activity behavior from individual, organizational, and governmental perspectives, examining environments such as schools, communities, factories, and nursing homes. This relatively comprehensive model laid the groundwork for later research. Corti (1998), building on previous models of physical activity, proposed a socio-ecological model specifically for walking behavior interventions. She argued that walking behavior is influenced by personal factors, social environments, and the physical environment. Personal factors include physical ability, attitude, and habits; social factors include peer influence and awareness of physical activity norms; and physical environment factors include accessibility to public spaces, stores, and pathways, as well as social and natural facilities. To further understand the environmental impacts on walking and physical activity, Spence (2003) proposed a more comprehensive model, integrating factors that influence

The fifth level is enjoyment, referring to the pleasure people experience while walking. This five-tier model explains the factors and decision-making order that influence walking as a transport mode. Notably, all but the first level are closely tied to the built environment. Thus, the model underscores the built environment's role in shaping transportation-related physical activity.

Jeff Speck is an American urban planner dedicated to the development of smart cities and sustainable design. In his 2012 book "Pedestrian Cities: Saving America by Creating Vibrant City Centers," he pointed out that walking must meet four main conditions: practicality, safety, comfort, and fun^[73]. The content of each condition is crucial and indispensable. Practicality "means that most daily living facilities are concentrated nearby and can be easily reached by walking. 'Safety' means preventing pedestrians from being hit by motor vehicles through street design; It is not only necessary to ensure the safety of pedestrians, but also to make them feel safe, which is even more difficult to achieve. Comfort "means that through the design of architecture and landscape, the street becomes an" outdoor living room "rather than an open space that is unattractive to pedestrians. 'Fun' means that the buildings on both sides of the street have different styles, pleasant facades, and are full of humanistic atmosphere. Jeff Speck further refined the theory of walkable urbanism into a systematic framework, summarized as the "Ten Steps to Achieve Walkability". The framework emphasizes controlling automobile dominance, promoting functional mix, adopting rational parking and transit strategies, and ensuring pedestrian safety and comfort through spatial form, greenery, and street design. It highlights that achieving walkability requires not only reducing car dependence but also integrating design, safety, and aesthetic dimensions into everyday urban life. Building on this, Speck's later work "Walkable City Rules: 101 Steps to Building a Better Place" expands the framework into a more actionable guideline comprising 101 rules across 19 themes. These rules address issues such as speed management, intersection density, the re-evaluation of Level of Service (LOS) standards, street and lane design, protected bike lanes, and micro-scale interventions like small parks and widened sidewalks. Collectively, these principles advocate a shift from car-oriented to people-oriented urban spaces, aligning closely with the goals of green mobility and neighborhood-level sustainability.

● Classic Cycling Theory

The classic cycling theory suggests that walking and cycling environments may differ, and a community that is highly suitable for walking may not necessarily be suitable

for cycling^[74]. Compared to walking, cycling involves more infrastructure, including bike lanes, parking spaces, public bike facilities, etc. For example, the traffic safety issue of cycling has always been one of the important factors for people to choose cycling as a mode of transportation. Setting up safe bike lanes to prevent motor vehicles from mixing with bicycles can help increase people's willingness to ride, especially women^[75]. Kerr J discussed measures to reduce cycling obstacles from four aspects: opportunity, accessibility and distance, safety, and physical environment (Figure 2.4). Building a cycling city requires coordinated and mutually supportive infrastructure, plans, and policies^[76].

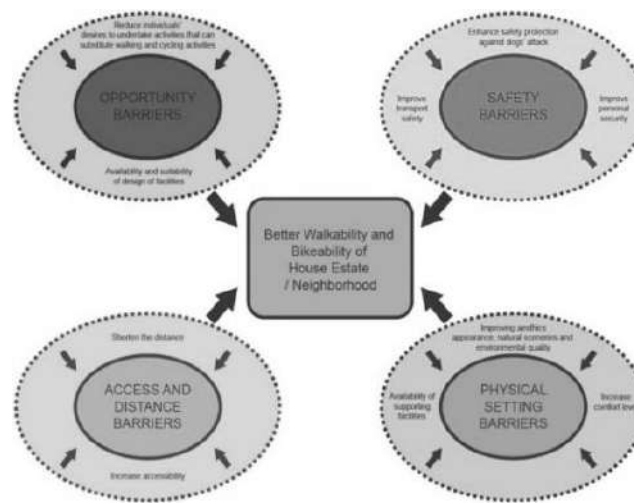


Figure 2.4 The built environment that helps overcome different types of barriers^[74]

(2) Practice

● International Planning Practice: Home Area, Game Street, and Complete Street

Since the 1930s, the concept of pedestrian priority in the UK has developed for nearly a century, forming a clear guiding ideology for pedestrian priority, a large amount of relevant academic research, and systematic legal and regulatory protection. In terms of local and national exploration, the Traffic Facilitation Law was promulgated in 1992, followed by the introduction of national policies. Carmen Hass Klau (2015) published the book "Pedestrians and Cities", which introduces the gradual development of pedestrian priority concepts in European and American countries, especially Germany, the United Kingdom, and the United States, and presents many practical cases worldwide.

Home area is a pedestrian first concept that emerged in the 1930s in the UK, advocating that quality of life is more important than traffic efficiency. Various speed

reduction measures have been taken to protect local pedestrians, bicycles, and residents. The academic community generally believes that the theory of home zone was first established in Delft, Netherlands in the 1960s, adopted by the Dutch government in 1976, and introduced to the UK in 1980. But in fact, as early as the 1930s, Britain had a game street theory similar to the later homeland area.

In 1977, the UK Department for Environment and Transport issued Design Notice No. 32: Residential Roads and Pedestrians: Layout Design, including guidelines for designing shared space forms for dead ends or short access roads. Combining road and landscape design with a large amount of shared space. The urban safety project was implemented in 1982 with the aim of reducing scattered accidents on residential streets and restricting transit traffic.

A complete street is a transportation policy and design concept that requires streets to be planned, designed, operated, and maintained to ensure that people of all ages and abilities, regardless of the mode of transportation used, can travel and use safely, conveniently, and comfortably. A complete street enables pedestrians, cyclists, drivers, public transportation passengers, or cargo carriers to travel safely.

● Domestic planning practice: pedestrian and green transportation policies

In China, pedestrian priority and green transportation have become the development concepts of urban renewal, and have been emphasized multiple times. The National New Urbanization Plan clearly proposes to develop green transportation and strengthen the construction of pedestrian and bicycle slow traffic systems. The National 13th Five Year Plan also requires promoting low-carbon development of urban transportation, prioritizing public transportation and pedestrian transportation, and encouraging green travel.

In recent years, China has implemented multiple policies that require the vigorous development of pedestrian systems and green transportation, especially in urban centers. The 2014 National New Urbanization Plan (2014-2020) identified "strengthening the construction of pedestrian and bicycle slow traffic systems" as one of the key focuses of green city construction. The 2015 Central Urban Work Conference proposed to promote the formation of green and low-carbon production and lifestyle, as well as urban construction and operation models. The 13th Five Year Plan for National Economic and Social Development of the People's Republic of China in 2016 proposed to strengthen the construction of urban pedestrian and bicycle transportation facilities. The Guiding

Opinions of the Ministry of Housing and Urban Rural Development on Strengthening Ecological Restoration and Urban Renewal Work in 2017 further proposed to "appropriately expand cities".

2.2.2 Green travel degree measurement and space distribution

"Measurement" research primarily focuses on indicators such as trip distance (e.g., vehicle miles traveled (VMT), trip frequency (e.g., proportion of green trips, proportion of different travel modes), trip time (e.g., vehicle hours traveled (VHT), energy consumption, and carbon emissions). This type of evaluation system primarily relies on quantitative analysis, focusing on measuring the low-carbon effects of transportation behavior through the dimensions of outcomes. However, detailed assessments of short-distance trips (e.g., walking within 1 kilometer) are insufficient, failing to fully capture the carbon reduction potential of micro-scale travel scenarios^[77].

"Distribution" research pays less attention to the spatial scope and patterns of different travel modes. Residents' daily travel distances fluctuate, with walking distances typically ranging from 400 to 1200 meters, and cycling distances typically ranging from 1.5 to 5 kilometers, with the majority occurring within 3 kilometers^{[78][79][80][81]}. However, research on the spatial patterns of walking and cycling (such as route selection patterns and node clustering characteristics) remains relatively scarce.

Most studies focus solely on the spatial extent of all modes of travel (i.e., at the residential quarter level), typically using a 50% percentage of trips as the threshold for defining a specific area^{[82][83][84]}. Significant differences exist between cities: the radius of a residential circle in Guangzhou is 0.8-1.8 kilometers, while in Beijing it is 5-12 kilometers. Existing research has mostly focused on measuring its range^[84], with only a few studies further summarizing spatial prototypes^[85] and distribution characteristics^[83].

2.2.3 Green travel preferences across diverse residents and residential quarters

The green travel preferences of residents are influenced by both neighborhood and individual attributes. Existing studies have shown that external factors such as community spatial structure, location conditions, and transport accessibility, along with individual characteristics such as family structure, age, gender, and socio-economic status, significantly impact residents' low-carbon travel choices.

(1) Green Travel Behavior in Different Types of Residential quarters

- **Community Type:** Compared to public housing and commercial residential quarters, residents of hutongs and unit-based communities exhibit higher green travel rates and lower transportation carbon emissions^{[86][87][88][89][89]}. These traditional neighborhoods typically have compact spaces and a high degree of functional mixing, which makes it easier for residents to meet their daily travel needs through walking or non-motorized transport.
- **Location Characteristics:** Suburban residents are more dependent on non-motorized transport. Studies have indicated that suburban attributes significantly increase residents' driving distances, accounting for 16% of total driving mileage. Additionally, new urbanism communities significantly influence women's travel behaviors, with daily steps decreasing by over 4000 steps^[90], indicating the substantial impact of residential patterns on travel behavior.
- **Transport Accessibility:** Proximity to public transport corridors is significantly associated with green travel choices. Studies have shown that residents near bus corridors are more likely to choose low-carbon transport options such as public transit and cycling.
- **Spatial Openness:** Gated communities, which reduce internal connectivity, have a negative impact on low-carbon travel choices^[91]. On the other hand, open residential quarters, by optimizing walking networks, enhance the convenience of non-motorized travel.

(2) Green Travel Differences Among Different Demographic Groups

- **Family Structure:** Multi-child households are more likely to rely on private cars, and the green travel rate decreases as the number of children increases^[92], reflecting how childcare needs restrict travel modes.
- **Age:** With increasing age, residents tend to reduce the distance for leisure travel and choose low-intensity travel modes like walking and public transit^[68]. The preference for green travel significantly increases with age.
- **Socio-Economic Status:** The influence of income and education level on green travel shows inconsistent findings. In cycling studies, some literature shows a positive correlation with income, while others report a negative correlation or no significant relationship. Similarly, in walking studies, some scholars suggest

that high-income, highly-educated individuals are more likely to walk, while others find lower walking intentions among these groups. These discrepancies may arise from differences in the development stage of cities and the purposes of travel.

- **Gender Differences:** Gender differences in green travel remain stable. Women drive less frequently than men, while young men are more likely to cycle. Gender has a greater negative effect on cycling than on walking^[92], reflecting how social roles and physical activity preferences influence travel mode choices.

2.3 Research of relationship between facility layout and green travel in living circle

2.3.1 Impact of the overall living circle environment on green travel

1 Impact of Facilities and Their Environment on Overall Travel

The relationship between the living circle's facilities and overall travel is generally positive, although some impacts remain unclear. The effect of different built environments on the choice of public transport varies. The use of public bicycles is primarily influenced by the density of daily service facilities, infrastructure, and public transport conditions within 300 meters of the station. Better public transport accessibility (measured by the number and distance of transport stations) correlates with increased walking activities related to transport, with probabilities ranging from 1.44 to 2.33 for those with better transport access compared to those with poor transport options^[93]. Functional diversity along the route promotes walking. Compared to 500 meters and 1000 meters, an increase in public facilities within 300 meters enhances the frequency of walking, cycling, and electric vehicle use. Accessibility of facilities, as one of the most critical land use indicators, significantly impacts travel behavior^[94]. All facility-related factors contribute to a reduction in vehicle mileage (VMT), with the accessibility of service facilities having an impact factor of 0.2^[95].

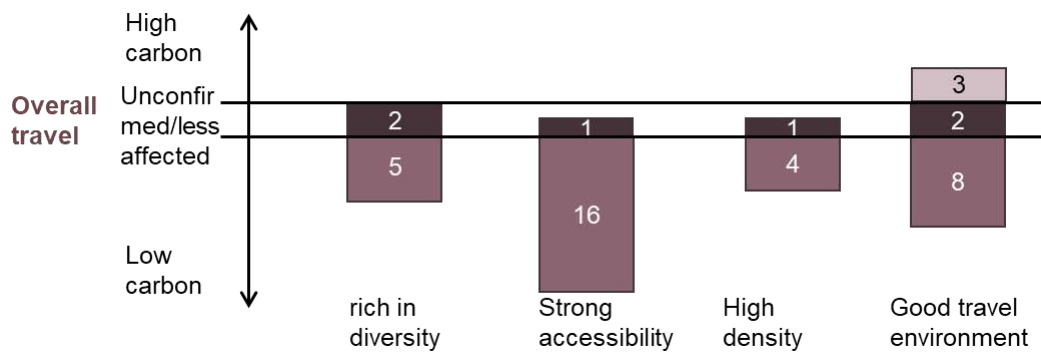


Figure 2.5 Impact of living circle facility layout indicators on travel modes

(Coverage is included in accessibility; travel environment refers to the environment near facilities, including public transport conditions, etc.). Source:

Author's drawing.

2 Impact of Facilities and Their Environment on Travel for Different Purposes

High-frequency activities (such as shopping, buying groceries, etc.) show a positive correlation, while low-frequency activities (such as dining, medical visits, etc.) are mainly unaffected (Figure 2.6). For some high-frequency activities, the facility layout significantly influences low-carbon travel, such as for grocery shopping, shopping, leisure, and education activities. Communities with diverse public facilities, high density, large quantity, and the highest coverage rates have the highest low-carbon travel proportions^[96]. For low-frequency activities, such as dining and medical visits, the impact of facility layout is debated, with some studies finding significant influence^[96] while others report a smaller effect^[68]. For ultra-low-frequency activities, such as banking, the impact is minimal.

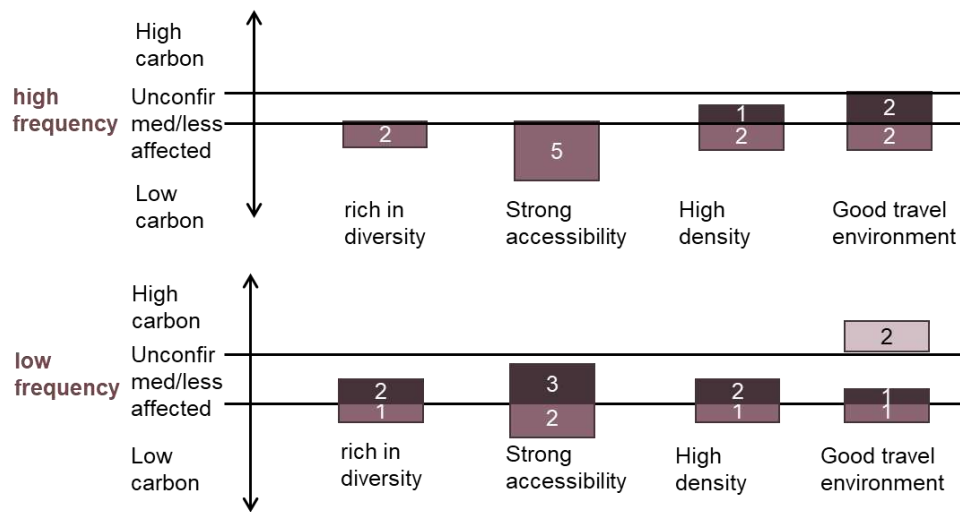


Figure 2.6 Impact of living circle facility layout indicators on travel modes for different purposes

(Coverage is included in accessibility; travel environment refers to the environment near facilities, including public transport conditions, etc. Based on related literature, self-drawn). Source: Author's drawing.

Overall, there are several shortcomings in this area of research: it tends to focus on single categories and indicators, lacking a systematic and comprehensive multi-indicator approach. The influence mechanisms of facilities, both overall and for specific purposes, remain unclear. There is limited research on low-carbon travel across different time periods, and the impact of the built environment on low-carbon travel varies depending on factors such as whether it is a working day or peak hours.

2.3.2 Impact of pathways on green travel

1 Walking

Many factors affecting walking remain controversial; however, school routes are a key focus of research, and the pedestrian perspective is a hot topic. Key influencing factors for facilities include street-side businesses^[97], while factors such as functional mix remain debated^[99]. In terms of the environment, significant factors include safety, while smaller impacts are attributed to connectivity^[100]. A central topic is the planning and design of school routes. A large amount of research on “school routes” already exists internationally^[101]. Recently, research has shifted to design factors from the pedestrian perspective, such as sidewalk coverage, average street width, building setbacks, and the

number of crosswalks.

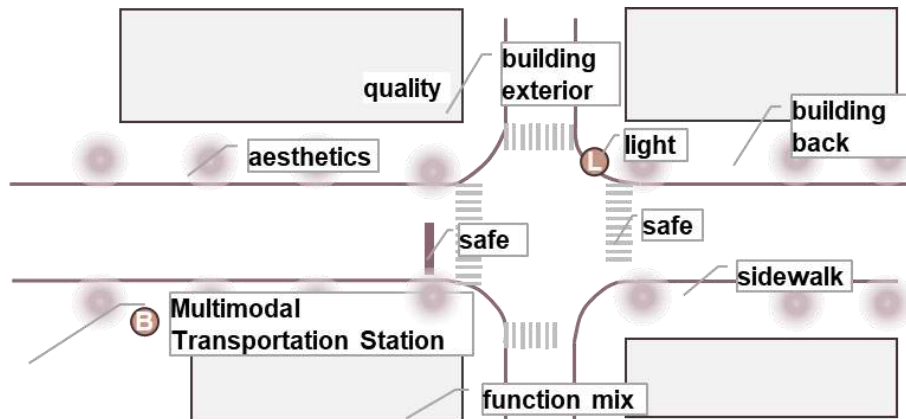


Figure 2.7 Factors influencing walking

Source: Author's drawing.

2 Cycling

Cycling paths have a significant influence, while soft environment factors have a lesser impact. There is less research on the facilities themselves. The major influencing factor for facilities is accessibility. In terms of the environment, significant factors include cycling paths^{[102][103]}, while factors such as road width and landscaping are debated. In recent years, research has focused on the impact of path environments on cycling under different weather conditions. Commonly accepted conclusions include that strong winds, rainfall, snow, and humidity negatively affect cycling, while the impact of temperature changes remains debated^{[104][105]}.

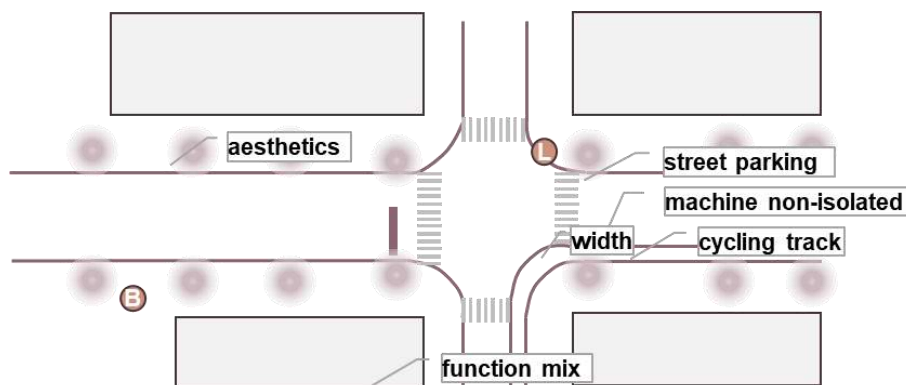


Figure Cycling Influence Factors (self-drawn)

Figure 2.8 Factors influencing cycling

Source: Author's drawing.

2.3.3 Impact of start and end points on green travel

1 Walking

Commercial facilities have a significant impact, while the influence of functional mix remains controversial, and the pedestrian perspective is dynamic. Regarding the facilities themselves, major influencing factors include commercial facilities^[106], sports facilities, parks (Millington), intersection density, and visibility; water bodies also significantly promote walking^{[107][108]}. Factors with smaller (contested) effects include functional mix^[109]. In terms of facilities and the environment, major influencing factors include population density, community entrance/exit density, block size (Doyle), street density, and connectivity. In recent years, research has shifted towards factors from a pedestrian perspective, such as crossing wait times, community entrance/exit density, and transparent (green) walls. Frequent travelers tend to live in high-density, commercially rich residential quarters along the street^[97].



Figure 2.9 Factors influencing walking

Source: Author's drawing.

2 Cycling

Station location has a significant impact, and different time periods show distinct trends. Regarding the facilities, significant factors include the density of stations, dining points, and retail stores; factors with smaller (contested) effects include the density of attractions and offices. In terms of the environment, major factors include population density and intersection density^{[110][111]}; factors with smaller (contested) effects include the functional mix near stations.

Notably, some studies found that the 300-meter range is crucial, with facilities within this range having a significant impact. Compared to the 500-meter and 1000-meter ranges, the number of public facilities within the 300-meter range increases the frequency of walking, cycling, and e-bike use. The use of public bikes is mainly affected by the density of daily service facilities, infrastructure, and public transport conditions within a 300-meter radius around bike stations.

In recent years, research has focused on whether there are peak-time and distance-related differences in start and end points^{[112][113]}. Based on these findings, different bicycle distribution strategies for various time periods have been proposed. For example, shared bike companies distribute bikes to metro stations near residential quarters before the morning peak, and then relocate them to various metro stations and main roads after the morning rush. These strategies are important for bike planning and management.

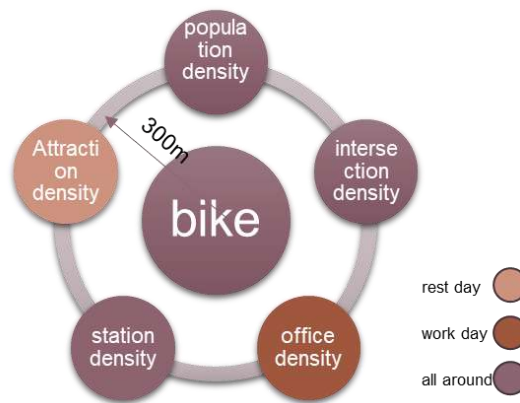


Figure 2.10 Factors influencing cycling

Source: Author's drawing.

2.3.4 Data and methods

1 Research Methods

In terms of quantitative research, most studies rely on data and focus on identifying patterns, general models, and statistical relationships. Common statistical methods include descriptive statistics and multivariate analysis. Multinomial logistic regression models are frequently used for modeling choices, such as transportation modes or destination selection. Some studies use correlation and variance analysis to identify relationships. Few studies employ advanced statistical modeling techniques, such as Structural Equation Modeling (SEM). A number of studies also utilize Geographic

Information System (GIS) tools for geographic visualization of spatiotemporal paths or activity patterns. Jiang Yang is one of the few scholars to use the dual-threshold variable method. In recent years, gradient decision trees have become a favored method among scholars.

For qualitative research, Naess is one of the few scholars to study the relationship between the built environment and travel behavior using qualitative methods. Although quantitative methods dominate the literature, qualitative research also holds significant value as it can capture potential or preference attributes that are difficult to quantify. Furthermore, some studies also apply qualitative methods such as the Theory of Planned Behavior (TPB) and Perceived Behavioral Control (PBC).

2 Data

The data used in studies are characterized by multi-sources and diversity, and the choice of methods is often determined by the data. Traditional data sources include official statistical data, survey data, and GPS activity logs, while new data sources include shared bicycles, subway and bus card swipe data, taxis, and mobile phone signals. Notably, walking and cycling path data can be divided into actual paths and virtual paths. Actual paths can be obtained from shared bike and mobile phone signal data; virtual paths are typically derived from services like Gaode Maps (shortest path).

In general, the common research methods predominantly involve traditional quantitative regression analysis, with limited use of geographic information visualization analysis. Research combining quantitative and qualitative analysis is rare, and most studies are based on traditional data and small sample sizes, particularly those involving path data. Most studies are observational and cross-sectional, with limited exploration of the causal effects of the built environment. In the 3324 studies reviewed, only 23 longitudinal studies explored the impact of the built environment on active mobility.

2.4 Summary

Despite substantial scholarly attention from multiple perspectives and scales, research on the correlation between living circle facility layout and residents' green travel remains insufficiently systematic, comprehensive, and fine-grained.

Overall, across hundreds of reviewed studies, the research scope typically centers on residential areas, 1-km buffers, or 3-km buffers to examine the correlation between the built environment and green travel. Existing studies predominantly emphasize built-

environment attributes while paying limited attention to facilities themselves, resulting in analyses that remain coarse and insufficiently in-depth. Even in studies that do consider facilities, the focus is often restricted to a single type or a small number of indicators, lacking a systematic multi-indicator framework. In many cases, the statistical scope for travel behavior is broader than the analytical scope for facility layouts, leaving unclear the mechanisms through which facilities within a specific area influence travel within that same area.

From content perspective, most studies remain at an aggregated analytical scale, with few adopting a process-based view of facility travel—that is, examining how road segments and origin/destination environments shape green travel behavior. Research based on pedestrian perspectives and school-route environments has only recently emerged. For origin/destination, existing studies mainly focus on difference of green travel and difference of influence mechanisms in different period or weather. Studies differentiating facility types are also scarce. For example, walking-related research commonly aggregates all travel purposes, examining correlations with overall facility density; few studies distinguish among shopping, healthcare, or school-related trips or explore the distinct mechanisms underlying each.

From method perspective, most existing research relies on traditional data sources such as GPS tracking or questionnaire surveys. Due to the difficulty and limited scale of collecting such data, study samples are typically small and restricted to a few types of residential areas. Analytical techniques are largely dominated by conventional linear regression models, which summarize only general tendencies rather than uncovering nuanced mechanisms. In terms of visualization, existing work mainly employs kernel density estimation or urban plan-view analyses, with limited visualization of community-level travel flow clusters or systematic summarization of representative facility-layout typologies. Collectively, these limitations result in research findings that are difficult to translate into planning practice and offer limited value for spatial renewal (Figure 2.11).

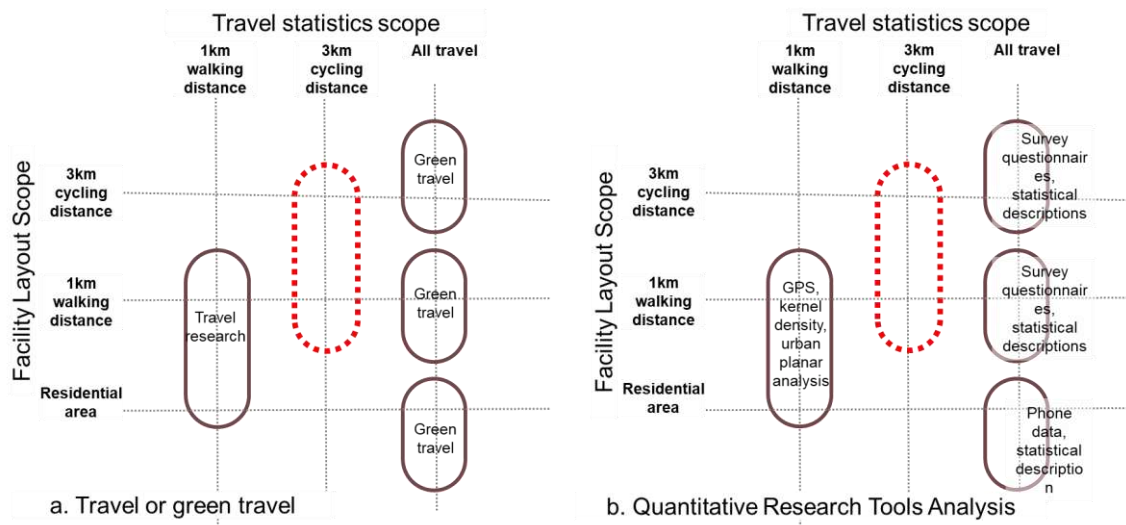


Figure 2.11 Weaknesses in existing empirical research

(Drawing: Author).

CHAPTER 3 CORRELATION THEORETICAL FRAMEWORK AND RESEARCH DESIGN

Based on the literature review, this chapter first introduces the methodology for mapping the 15-minute cycling living cycle, which serves as the technical foundation for the entire article. Secondly, it reviews theories such as the 15-minute city and constructs a cognitive framework for the correlation between facility layout and travel behavior within the living cycle, which serves as the theoretical foundation for the entire article. Finally, this chapter adheres to this cognitive framework to conduct an empirical research design and briefly introduces the methodology and data.

3.1 Technology foundation living circle delineation

3.1.1 Map navigation method

Previous studies have defined living circles as road-bound parcels, simplified residential circular buffers, or actual travel ranges^[112]. However, none of these accurately represent the true 15-minute living circle.

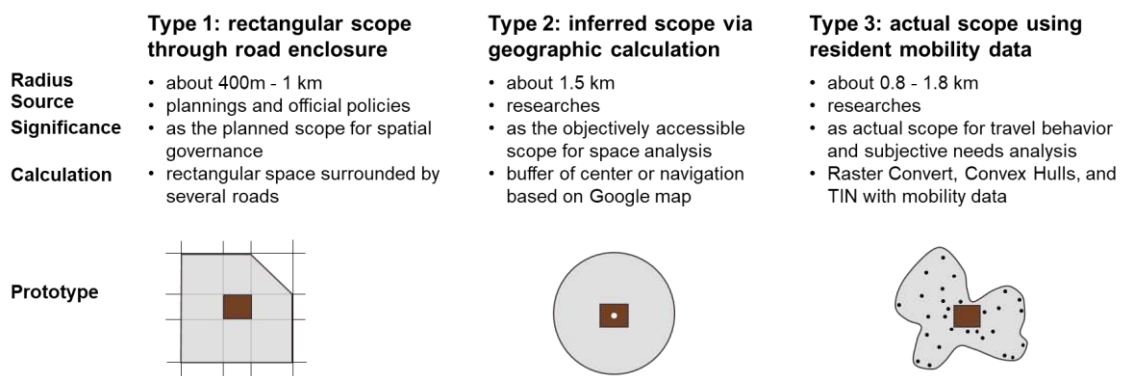


Figure 3.1 Existing methods of defining the living circle

This study proposes a method for defining a 15-minute residential living circle. The method uses the residential land centroid as the starting point, with a travel time of 15 minutes, cycling as the mode of transportation, and the default navigation speed from Gaode Map.

Taking TC101 as an example, this residential quarter is located on the northern side of the city center, a well-known affluent area with an average price of 24,000 CNY per square meter. The residential quarter consists of villas and apartments (Figure 3.2) and accommodates 900 households, with a total construction area of 307,692 square meters. TC101 is a square plot, a closed residential quarter with evenly distributed entrances and exits, making it representative and suitable as a case study. Using the aforementioned method, a 15-minute walking circle was drawn, and both the walking and cycling circles for TC101 are shown in the Figure 3.3 below. The 15-minute walking and cycling circle of TC101 residential quarter are about 1 km and 3 km.

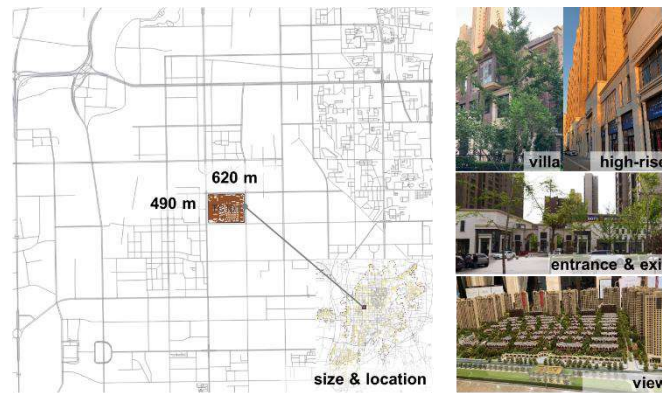


Figure 3.2 Tangcheng 101 block

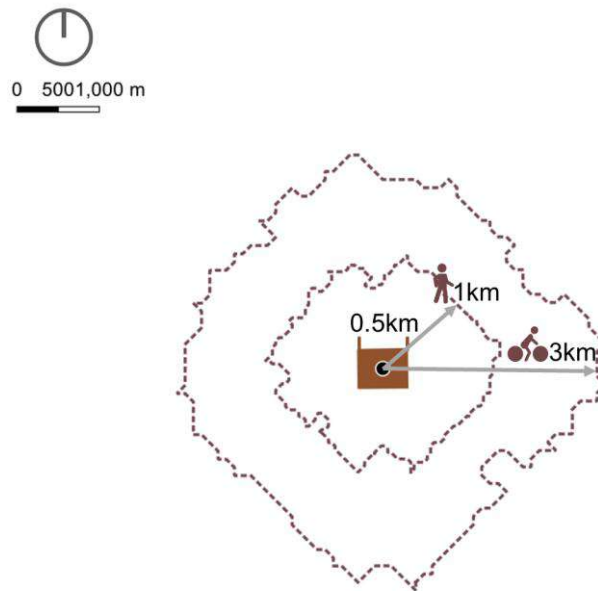


Figure 3.3 15-minute walking and cycling circle ranges for the TC101 residential quarter

Based on TC101 residential quarter, the method for defining the 15-minute cycling living circle using the Gaode Map API consists of six steps (Figure 3.4):

- 1 Draw the boundary of the residential land and extract the centroid of the residential land as the starting point. The latitude and longitude coordinates are used to draw a 15-minute isochrone around this point.
- 2 Based on the centroid, draw a circle with a radius of 4500 meters (slightly larger than the 15-minute cycling distance to ensure the destination points fall within the grid, thus completing the boundary), and generate a grid with 100-meter spacing. Each grid point serves as a simulated destination, with its latitude and longitude coordinates prepared for the next step of calling the Gaode Map routing API.
- 3 Call the Gaode Map API's route planning interface, using Gaode's cycling navigation algorithm to obtain distance and time information from the starting point to each destination.
- 4 Retain points with travel times less than or equal to 15 minutes or those close to 15 minutes.
- 5 Use Python to generate a closed boundary.
- 6 Obtain the 15-minute cycling living circle for the residential quarter.

The method can automatically generate living circles for any residential quarter, any travel mode, and any travel time, with the advantage of being simple, efficient, and easily applicable. The details are introduced in APPENDIX B.

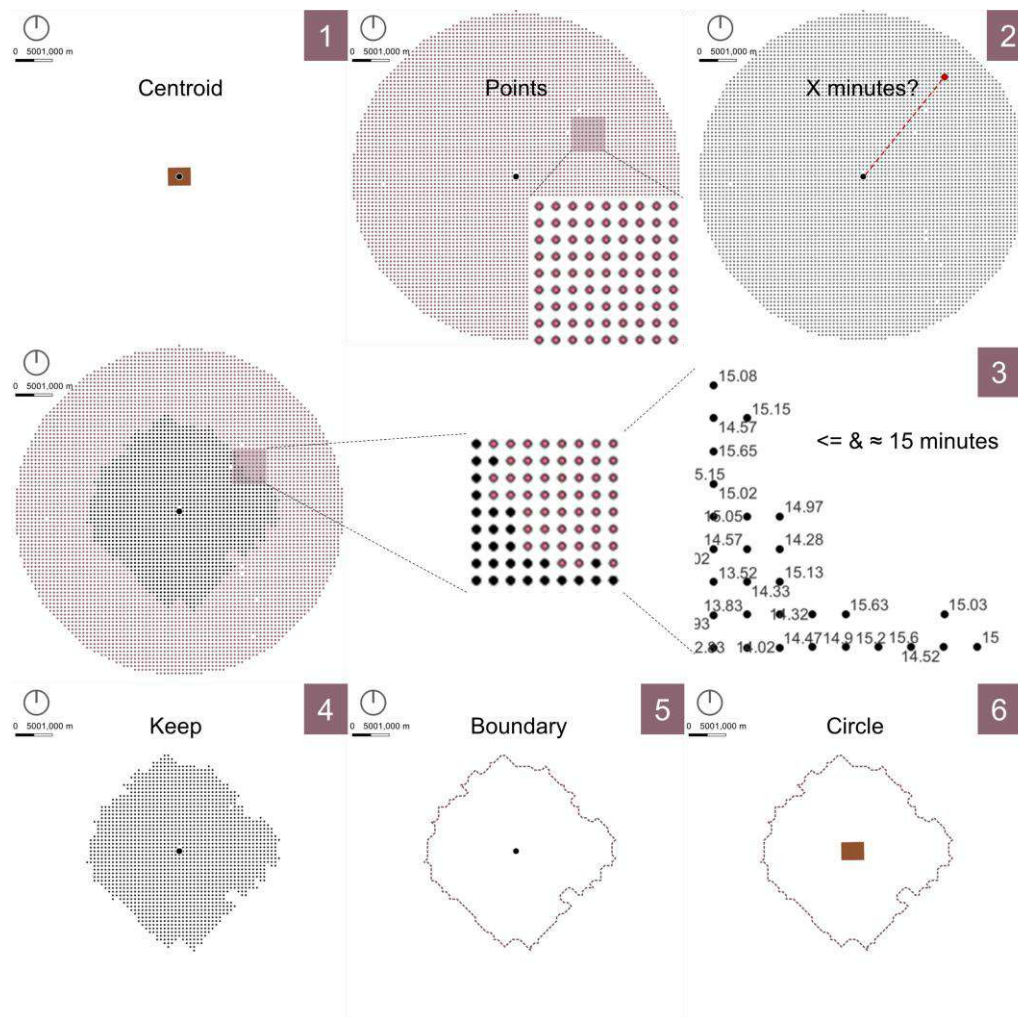


Figure 3.4 15-minute cycling circle drawing process

3.1.2 860 15-Minute living circles delineation

For each residential quarter, its 15-minute cycling living circle is drawn, there are 860 circles at all (Figure 3.5). These 15-minute cycling circles form the basis for subsequent screening of travel data and green travel measurements. Here 10 circles selected from 860 circles are shown to describe how the travel data are clipped (Figure 3.6). Because this study is limited to trips within the 15-minute cycling circle, when screening the data, for any residential quarter, only trips starting from the residential quarter and ending within the 15-minute cycling circle were retained, rather than trips ending within the entire city.

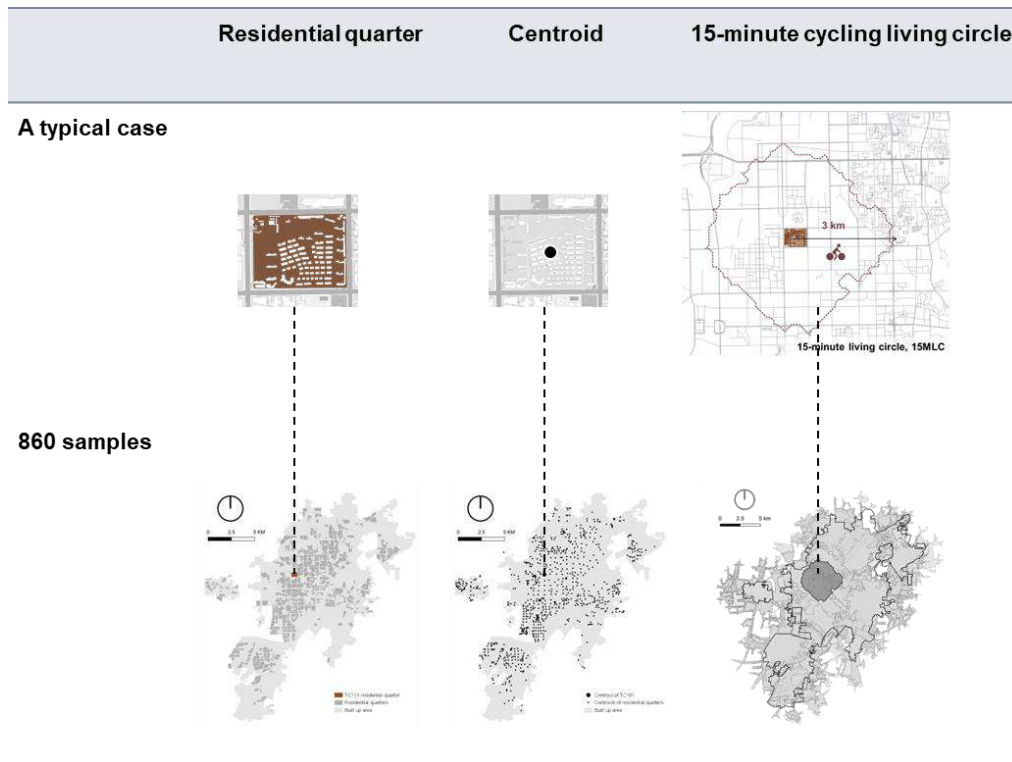


Figure 3.5 Tangshan 860 residential quarters, the centroids of them and their 15MLCs.

Source: Drawn by author.

For example, in Chapter 4 all-type green travel study, this 15-minute cycling circle boundary was used to calculate the green travel ratio of residential quarters within the boundary, measure the green travel level of residential quarters, and also serve as the statistical boundary for facility layout, such as the diversity of 14 types of facilities within the 15-minute cycling circle.

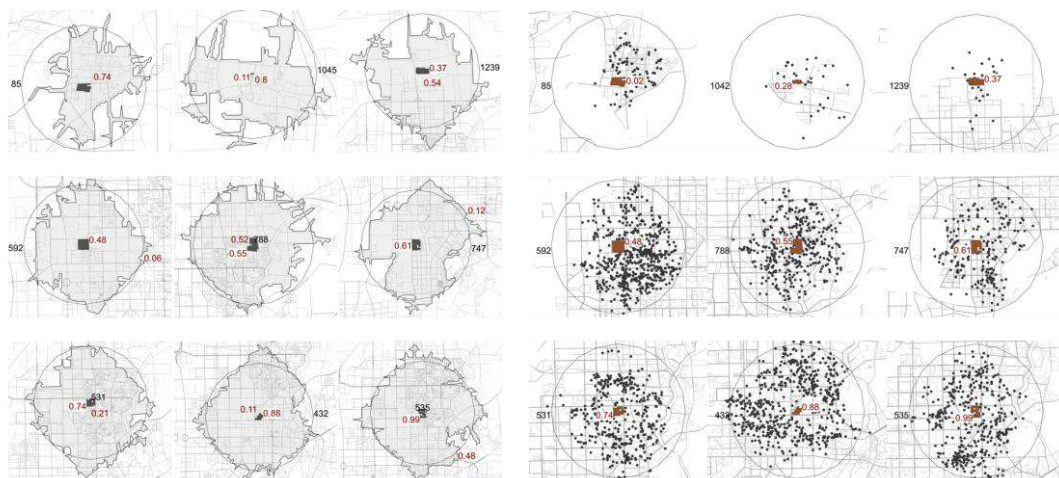


Figure 3.6 15-minute living circle range (left) and travel data filtered according to the range

(right)

From small to large, with Black Text Indicating Number and Red Text on White
Background Representing Living Circle Area Percentiles

3.1.3 Circles ranges comparison

The statistical results of 860 15-minute cycling living circles in Tangshan show significant variation in living circle size, with the largest being approximately 32.7 km² and the smallest less than 1 km² (Figure 3.7). A typical plot of land in Tangshan is 500 meters squared, with a 15-minute cycling living circle having a radius of approximately 3 kilometers, typically covering 5-6 blocks centered around a residential quarter. A 15-minute walking living circle has a radius of approximately 1 kilometer, with a 15-minute cycling living circle typically covering 2-3 blocks centered around the residential quarter. Area, compared to perimeter, better reflects the extent of a living circle, so this study uses area (area_iso) as the core indicator.

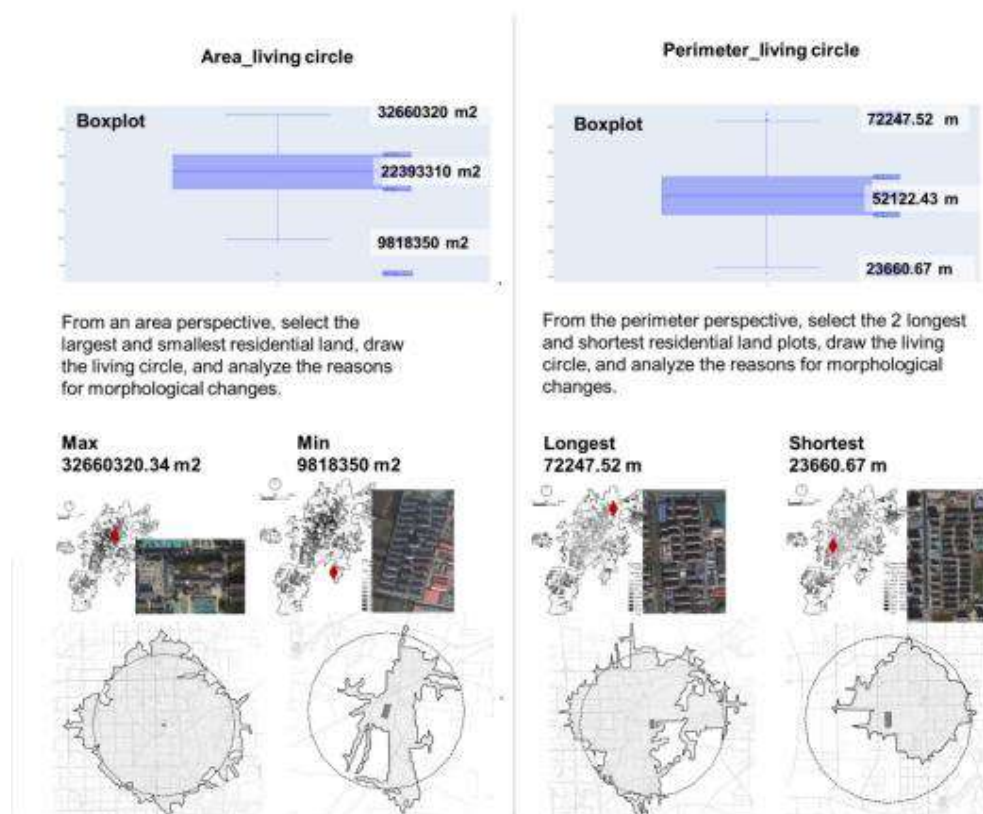


Figure 3.7 Boxplots of areas and perimeters of living circles.

Source: Drawn by author.

The difference in the size of living circles mainly comes from planning factors such as road network density, plot size and community entrance and exit organization: the central urban area forms a larger living circle due to the dense road network and compact travel, while the suburbs have a smaller scope due to the sparse road network and insufficient entrances and exits (Figure 3.8).

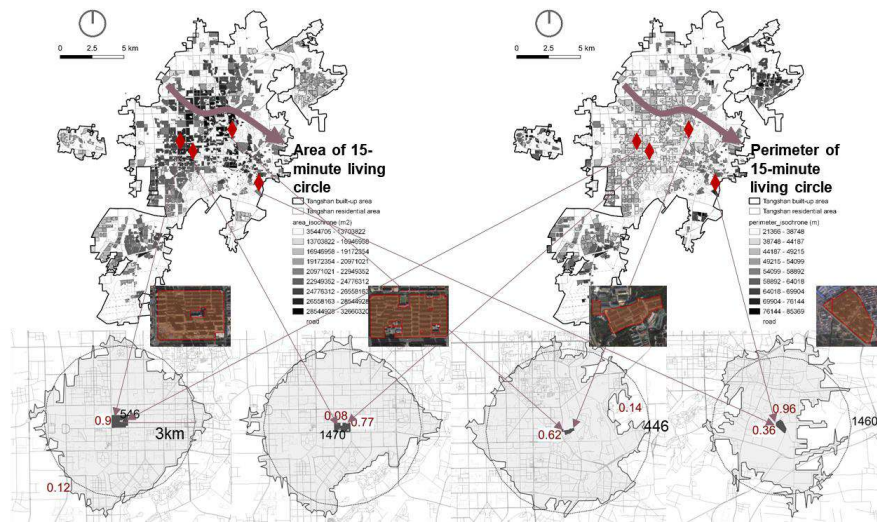


Figure 3.8 The effect of distance from the residential centroid to the city center on living circle area, with black text indicating ID and red text on white background representing living circle area percentiles

The living circle 'area' is included in the independent variable indicator system of all green travel research as a control variable 'area_iso' to eliminate the interference of different ranges on travel distance and green travel proportion.

3.2 Theoretical foundation

This thesis recalls the theories of planned behavior, the 15-minute city theory, the Huff model, and the 5D theory and so on, as these theories explain the type, stage of green travel, and dimensions affecting the green travel, encompassing the foundation of theoretical framework correlation between green travel and facility layout in the 15-minute cycling living circle.

3.2.1 Travel process theory

The Four-Step Travel Demand Model was first proposed by the U.S. Transportation Research Board (TRB) and the Federal Highway Administration (FHWA) in the 1950s and 1960s. With the rapid urbanization and the booming automotive industry post-World War II, cities in the U.S. faced increasing traffic congestion and environmental problems. City planners and transportation authorities urgently needed a scientific, systematic model to predict and guide future transportation demand and develop rational transportation planning policies and infrastructure layout schemes (Table 3.1).

The core concept of the Four-Step Travel Demand Model is to systematically divide the process of predicting urban residents' travel behavior into four interconnected and progressive stages: **Trip Generation**, **Trip Distribution**, **Mode Choice**, and **Route Assignment**.

- (a) **Trip Generation:** The objective of this stage is to predict the total volume of trips generated or attracted by a specific area during a given time period. The trip generation is generally determined by land use (such as residential, office, commercial, etc.) and socio-economic characteristics of the population (such as family size, income, car ownership, etc.). Common methods used include regression analysis, classification analysis, and cross-classification.
- (b) **Trip Distribution:** This stage determines how the travel demand generated in the trip generation stage is distributed between origin-destination (OD) pairs. The most commonly used method is the **Gravity Model**, which assumes that the amount of trips between any two regions is proportional to the strength of travel generation and attraction between the two regions, and inversely proportional to the travel impedance (such as travel time or distance). Additionally, the **Fratar Model** and other models are also applied in practice.

- (c) **Mode Choice:** After determining the distribution of trips between origin and destination, this stage predicts the probability of residents choosing different modes of transportation (such as cars, public transport, walking, cycling). Discrete Choice Models (e.g., **Logit** and **Nested Logit** models), based on Random Utility Theory, are generally used to analyze the comprehensive trade-offs and decision-making process of travelers regarding factors such as cost, convenience, and comfort of different modes of transport.
- (d) **Route Assignment:** The final stage is to assign the travel demand to specific roads or transport routes in a given transportation network, determining the traffic flow on each road. Classic network assignment methods include **All-or-Nothing Assignment**, **User Equilibrium Assignment**, and **System Optimal Assignment**. This stage uses iterative methods to determine the traffic load on each road segment in the network, assess whether the infrastructure capacity meets the demand, and guide the development of urban transportation network improvement plans.

Table 3.1 Four-Stage Travel Demand Forecasting Model components

Stage	Core Question	Common Methods	Typical Output
① Trip Generation	How many trips are generated/attracted by a zone?	Regression, Gravity Model, Piecewise Linear	OD Trip Totals
② Trip Distribution	How are trips distributed among OD pairs?	Gravity/Opportunity Model, Entropy Maximization	OD Matrix
③ Mode Choice	Which transport mode do travelers choose?	Logit / Nested Logit	Mode Share Rates
④ Route Assignment	Which routes are chosen within the network?	UE/ SUE、DTA	Link Volumes, Saturation Degree

Since the 1960s, the Four-Step Travel Demand Model has become a classic and standard tool in global transportation planning practices, widely applied in urban transportation infrastructure planning, traffic congestion and environmental impact assessments, and public transport system optimization. While newer theoretical paradigms like the **Activity-based Model** have emerged, the Four-Step model remains one of the most widely used models in international transportation forecasting due to its clear framework and stable, mature methods. It still forms the underlying framework of

most macro-transportation planning software (e.g., TransCAD, VISUM, Emme).

The implications of this theory for this study are that the **Trip Distribution** and **Mode Choice** steps of the Four-Step Travel Demand Model inspire the separation of **single-facility travel** into two stages: the **first stage of destination choice** and the **second stage of green travel mode choice**.

- **First stage: Destination choice** refers to predicting the distribution of trips from residential quarters to specific destinations (e.g., a supermarket), which can be influenced by facility characteristics, travel impedance, and residential quarter characteristics. The travel distribution within the living circle may affect green travel, such as the total travel distance or the distance to a specific facility.
- **Second stage: Green travel mode choice** refers to predicting the probability of choosing different modes of transportation (e.g., car, public transport, walking, cycling) for a defined destination, which may be influenced by characteristics of the residential quarter, the destination, or the surrounding environment.

In this study, based on this theoretical framework, we divide the study of **single-facility travel** into two stages, leading to two separate research areas: **the relationship between destination choice and facility layout** and **the relationship between green travel mode choice and facility layout**.

3.2.2 Destination choice and facility layout correlation theory

(1) Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB), developed by American social psychologist Icek Ajzen in 1985, is an extension of his earlier Theory of Reasoned Action. This theory emerged in response to the growing interest in predicting human behavior and understanding the psychological mechanisms behind decision-making.

The core concept of TPB is that the most direct and significant prerequisite for behavior is **behavioral intention**, which is influenced by three factors: **attitude**, **subjective norms**, and **perceived behavioral control**. Specifically:

- **Attitude** refers to an individual's positive or negative evaluation of a specific behavior, including how favorable or unfavorable they perceive the behavior to be. For example, if an individual views cycling as an environmentally friendly and healthy option, they are more likely to have a positive attitude toward

cycling.

- **Subjective Norms** refer to the perceived social pressure from significant others or groups around the individual, i.e., how the social environment expects the individual to perform or not perform a particular behavior. For example, when residents perceive that their friends and neighbors encourage public transport usage, it increases their intention to choose public transport.
- **Perceived Behavioral Control** refers to an individual's perception of how easy or difficult it is to perform a specific behavior. This factor is related to the individual's perceived ability or barriers to engaging in the behavior. For instance, even if a resident wants to cycle, if they perceive the cycling environment as unsafe, their intention to cycle will decrease.

As a clear and structured model for predicting behavior, TPB has been widely applied in health behavior, environmental behavior, and transportation studies. This theory is particularly useful in predicting and guiding public behavior. The insights from TPB for this study suggest that the attitudes of residential quarter residents towards green travel influence their mode choice. Residents with positive attitudes towards walking and cycling are more likely to choose green travel options when other living circle environmental conditions remain the same. In this study, TPB is applied to the fifth and sixth chapters, where a green travel attitude indicator is set within the attitude dimension, along with other facility layout indicators, to explore their impact on green travel.

(2) Huff Model

The Huff Model was proposed by American geographer and marketing scholar David L. Huff in 1963^[119]. Originally introduced in the context of rapidly growing retail industries and the competitive urban commercial centers, Huff's model aimed to predict consumer shopping behavior and optimize the layout of commercial facilities (Figure 3.1).

The core idea of the Huff Model is that the probability of a consumer choosing a shopping center is directly proportional to the size (attractiveness) of the center and inversely proportional to the distance (cost) to the shopping center. The mathematical expression is:

$$P_{ij} = \frac{\frac{S_j^\alpha}{D_{ij}^\beta}}{\sum_{j=1}^n \frac{S_j^\alpha}{D_{ij}^\beta}} \quad (3-1)$$

- P_{ij} represents the probability of consumer i choosing supermarket j ;
 - S_j represents the scale or attractiveness of supermarket j ;
 - D_{ij} represents the distance or travel cost from consumer i to supermarket j ;
- α and β represent the sensitivity coefficients for supermarket size and distance, respectively, which are used to adjust the attractiveness and hindering factors in different contexts.

The Huff Model has found extensive application in geography and urban planning, particularly in retail center layout, commercial area location planning, public service facility site selection, and market share forecasting (Figure 3.9). It remains one of the classic models in spatial facility planning. This theory has implications for this study in that, for single-facility travel destination choices, the selection of a facility (e.g., a supermarket) depends on the facility's characteristics (attractiveness) and travel costs. By using real travel data, the attraction and travel cost sensitivity coefficients can be derived to compare the destination choice patterns for different types of facilities. In this study, Chapter 6 applies the Huff Model to validate the significant role of facility scale in destination selection and long-distance travel, comparing the scale sensitivity coefficients and distance sensitivity coefficients of supermarkets and markets.

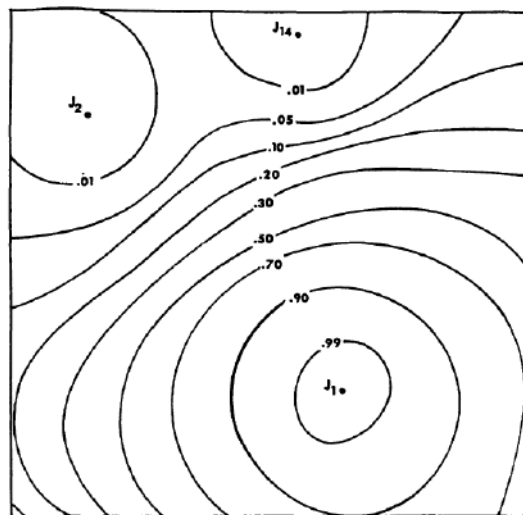


Figure 3.9 Probability service areas of shopping centers in Huff Model

(3) Living Circle Theory

Globally, the concept of Living Circle Theory is not a description of the surrounding environment of settlements, but rather an urban-level territorial planning theory. The concept was first introduced by Japanese scholar Ishikawa Nobuyoshi in 1939 during the

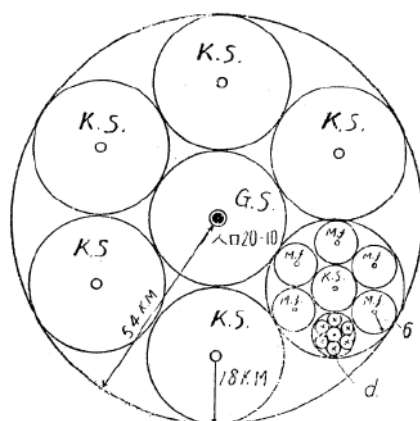
levels of centers has remained consistent.

第1表 石川栄耀と彼が引用したドイツの研究例に見られる生活圏の特徴
Table 1 Characteristics of Ishikawa's life-area and the German one cited by Ishikawa (1942b)

石川 (1941b)			石川(1942b)で引用されたドイツの例			参考: Christaller (1933a) の $k=3$ の中心地システム*		
中心集落の名称	生活圏の半径(km)	中心集落の人口(万人)	中心集落の名称	生活圏の半径(km)	中心集落の人口(万人)	中心集落の名称	生活圏の半径(km)	中心集落の人口(万人)
月末級の生活中心	45	20	Gaustadt	54	10~20	G 中心地	54	3
週末級の生活中心	15	5~10	Kreisstadt	18	2	B 中心地	18	1
日常生活中心	5	2	Markt-flecken	6	0.1	A 中心地	6	0.2
			Dorf	2	0.01~0.04	H 中心地	2	0.08

* Christaller の生活圏 (六角形の補完区域内に内接する円形地域に相当) は、石川の生活圏シェーマにならない、財の未供給地域が存在を前提にして設定した場合のものである。

Figure 3.11 Ishikawa Nobuyoshi's evolution of Living Circle Theory^[121]



- G.S.=Gau Stadt
人口 20—10萬, 領域半径 54km.
大學等あり. 中心なり.
- K.S.=Kreis Stadt.
人口 2 萬, 領域半径 18km.
工業を主とす. 地方構成上の重要點.
- M.f.=Markt flecken
人口 1000, 領域半径 6km. 農業中心.
- × d.=dorf.
人口 400—100, 領域半径 2km. 農村.

第3図 ドイツ版生活圏シェーマ
(石川, 1942b, p. 126).

本図の転載にあたっては、すでに著者、編者、出版社のいずれも存在していないので、故石川栄耀先生のご子息・石川 允先生(東京電機大学)に、1996年9月30日付でご許可をいただいた。

Fig. 3 German schema of life-area

Figure 3.12 Nested diagram of Ishikawa's glory Living Circle Theory^[121]

The concept of the living circle has drawn attention to the structure of life^[122] (Figure 3.10(b)), gradually evolving into the "Wide Area Living Circle," which influenced national planning in Japan, including the 1965 "Second National Comprehensive Development Plan." This plan aimed to distribute infrastructure and service facilities to promote balanced regional development^[123].

In Ishikawa Nobuyoshi's Living Circle Theory, the relative positioning of the central villages and the hierarchical system of central places in the Central Place Theory, based on administrative principles, are similar in spatial layout^[124]. A higher-level center's service area completely encompasses the service areas of seven lower-level centers. According to the $K = 7$ administrative principle (or political-social principle), the market area of a smaller settlement is entirely enclosed within the market area of a larger settlement, and a larger settlement consists of six to seven smaller settlements. Because the surrounding areas cannot be administratively divided, they must be assigned to a higher-level region. Efficient management is the control principle of this hierarchical system (Figure 3.13).

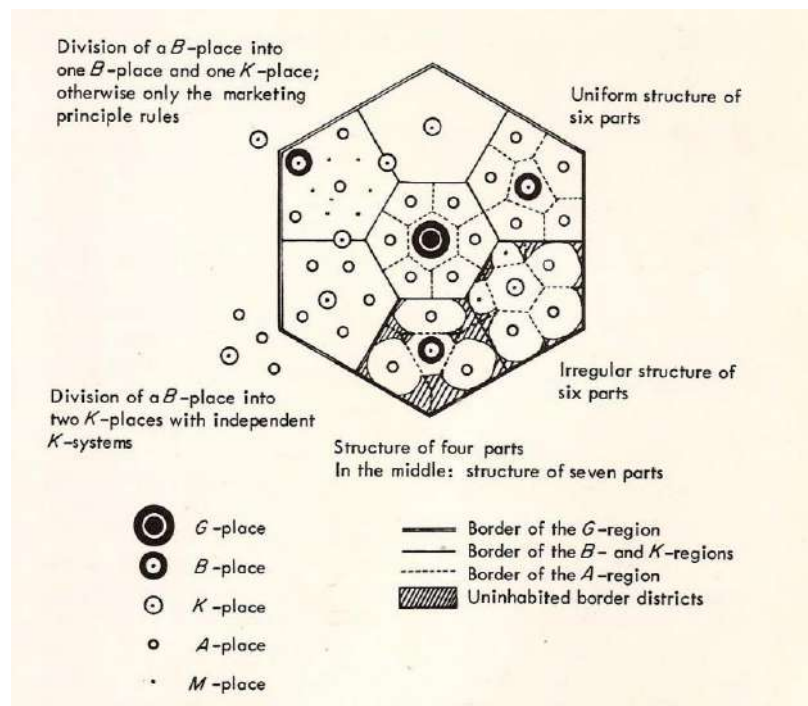


Figure 3.13 In the Central Place Theory under the administrative principle, a higher-level center consists of six to seven secondary centers^[124].

This theory's contribution to this research lies in the concept that living circle planning uses the city as a base map, with living centers acting as the key points. There

is a hierarchical relationship between high- and low-level centers, with a constant numerical ratio between them, as well as a constant radius relationship between high- and low-level centers. In Chapter 6 of this study, regarding the layout and travel analysis of single facilities, facilities are categorized based on their size, and the travel distance characteristics of each level of facility are analyzed to verify that size is a significant factor contributing to long-distance travel. Additionally, drawing on the "residential quarter as the center" perspective, the study analyzes travel distance characteristics between the residential quarter and various levels of facilities based on residential quarter-to-facility OD flow clusters.

3.2.3 Green travel mode choice and facility layout correlation theory

(1) 15-Minute City Theory

The 15-minute city theory moves away from a facility-centered approach and focuses on a human-centered facility layout. The 15-minute city (*ville du quart d'heure*) is one of the new "time urbanism" concepts in city planning. Its goal is to allow urban residents to fulfill most of their daily needs—such as food, housing, education, and entertainment—within a 15-minute walk or bike ride. The concept was introduced by Colombian-born French scholar Carlos Moreno in 2016, aiming to reduce commuting time and improve the convenience of daily life^[125].

Drawing on theories from the 20th century, such as Perry's neighborhood unit theory, Le Corbusier's Chandigarh urban model, and Jane Jacobs' concept of mixed-use communities, the 15-minute city integrates six key functions: housing, employment, shopping, healthcare, education, and entertainment. Moreover, it considers four main dimensions: (a) Density, (b) Proximity, (c) Diversity, and (d) Digitalization (Figure 3.6). These dimensions were formulated after observing the challenges faced by global cities during the peak of the COVID-19 pandemic and the measures adopted to reduce transmission. These cities, by prioritizing these four dimensions within a comprehensive and flexible framework, were able to avoid many issues.

(a) Density: The 15-Minute City theory posits that traditional planning for super-tall buildings and offices poses challenges, including increased overconsumption of resources and excessive reliance on fossil fuel energy to power buildings, ultimately leading to an increase in the number of cars inspired by centralized planning ideas. Unlike traditional planning, which emphasizes ultra-high-density buildings, the 15-Minute City theory

emphasizes appropriate density, "the optimal density that ultimately allows for sustainable development at the economic, social, and environmental frontiers." That is, in terms of urban service provision and resource consumption, it is crucial to consider the optimal number of people that a specific area can comfortably sustain.

This optimal density can effectively plan available space, create local solutions, reduce long-distance travel to high-density areas, and enable residents to obtain basic essential services without wasting time and energy (driving). Public infrastructure, such as bicycle lanes and pedestrian paths, should be reasonably constructed to minimize the demand for cars. At the same time, it is particularly beneficial to vulnerable groups, especially through the equitable distribution of municipal services and the deployment of services to cities at lower costs, including communities with different economic conditions, which has higher value for both investors and governments. Density is a key factor conducive to the sustainability dimension of urban society. When combined with the other three dimensions (proximity, diversity, and digitization), the "15-minute city" model not only helps improve service delivery and enhance livability, but also benefits from advanced technological advancements.

(b) Proximity: The proximity emphasized in the 15-minute city theory underscores the dual dimensions of time and space, implying that residents should be able to reach essential service facilities within a 15-minute radius. This dimension not only effectively reduces commuting time but also mitigates its negative impacts on the environment and economy. Proximity fosters social interaction, enhances connections among residents, and boosts the social capital and cohesion of the city. By offering convenient multimodal travel options, proximity enables residents to make better use of public spaces and green spaces, while ensuring that various communities have equal access to infrastructure resources. When combined with other dimensions such as density and diversity, proximity serves as a crucial pillar in promoting sustainable urban development^[126].

(c) Diversity: Within the framework of the 15-Minute City, diversity encompasses two aspects: firstly, providing multifunctional spaces such as residential, commercial, and recreational areas through mixed-use communities, and secondly, promoting cultural and demographic diversity. Mixed-use communities can enhance economic vitality, strengthen urban inclusivity, promote sustainable development, and ensure optimal density and proximity to basic services. Diversity also provides residents with richer cultural experiences, enhancing social cohesion and participation in the community.

Furthermore, a multicultural urban environment has a positive impact on economic development, attracting tourists and investment, thereby promoting economic vitality and creating job opportunities. Combined with density and proximity, diversity is a core element in achieving the "15-Minute City" model.

(d) Digitization: Digitization serves as a crucial backbone for the 15-minute city, especially in ensuring the realization of the other three dimensions. Leveraging smart city platforms and digital tools, digitization enhances the efficiency and inclusivity of urban services, reduces commuting needs, and elevates residents' quality of life. The application of digital technologies, such as shared bicycles, intelligent transportation systems, and online services, fosters green travel and diminishes reliance on private cars. Simultaneously, digitization bolsters urban resilience in areas like emission reduction and climate change adaptation, propelling sustainable urban development. As a cross-cutting element, digitization permeates and facilitates the implementation of density, proximity, and diversity, ensuring the successful transformation of the 15-minute city^[127].



Figure 3.14 Four dimensions of the 15-minute city

The 15-minute city theory's application in this study suggests that the layout of facilities within residential circles can be described through three key dimensions: facility density, facility diversity, and facility proximity^[128]. Additionally, the core principle of the 15-minute city, multi-centered proximity, implies that urban centers should be

diversified to avoid a single-pole facility layout. This concept is applied in Chapter 4, where facility layout indicators, including the city center, are used to assess different residential circles' facility layout characteristics and locations.

(2) 5D Theory

The potential to regulate travel demand by altering the built environment is one of the most intensively studied topics in urban planning. In travel research, such impacts are often named after words starting with the letter D. The original "3D" was proposed by ^[129]Cervero and Kockelman (1997), representing density, diversity, and design, followed by destination accessibility and travel distance^{[130][131]}. Demand management (including parking supply and cost) is the sixth D, included in some studies. Although not part of the environment, demographics can be considered as the seventh D, controlled as a confounding effect in travel research.

The "3D" model (Density, Diversity, and Design) proposed by Cervero and Kockelman (1997) aimed to address the impact of urban design concepts on travel demand at that time (Table 3.2). With the rise of new urbanism, Transit-Oriented Development (TOD), and traditional town planning concepts, these design ideas emphasize changing residents' travel patterns by transforming the urban built environment, especially in reducing car use and promoting green travel. They share three common transportation goals: (1) reducing the number of motorized trips and decreasing dependence on cars; (2) increasing the proportion of non-motorized travel, promoting walking or cycling; (3) within motorized travel, reducing travel distance and increasing vehicle occupancy rates, supporting public transportation and carpooling.

Against this backdrop, the 3D model proposed by Cervero and Kockelman emphasizes guiding residents to reduce their dependence on cars by increasing urban density, land use diversity, and improving design (such as pedestrian-friendly public spaces and compact community layouts), thereby achieving goals such as reducing environmental pollution and social isolation. Although the impact of density on travel demand has been studied before, the impact of diversity and design has been overlooked. Cervero and Kockelman's research is the first attempt to quantify the impact of these three dimensions on travel demand through factor analysis.

Table 3.2 Indicator system at the time of the 3D Model's Proposal

3D	Indicators
I. Density	● Population density: population per developed acre ● Employment density: employment per developed acre ● Accessibility to jobs: expressed in a gravity model form; for zone i, Accessibility Index = $(\text{jobs}) * \exp[A t_i]$, where i is the origin (residential) traffic analysis zone, j is the destination traffic analysis zone, t_i is travel time between zones i and j, and A is an empirically derived impedance coefficient. The accessibility index serves as a proxy for relative proximity and compactness of land uses.
II. Diversity	● Dissimilarity index: proportion of dissimilar land uses among hectare grid cells within a tract. For each tract, computed as: $(X/) / K$, where K = number of actively developed hectare grid-cells in the tract, and = 1 if the land-use category of the neighboring (i.e., abutting or caddy-corner) hectare grid-cell differs from hectare grid-cell j (0 otherwise). (See Fig. 2) ● Entropy: mean entropy for land-use categories among hectare grid cells within a half-mile radius of each hectare grid cell within a tract. For each tract, computed as: $[P \ln(pik)] / \ln(K)$, where: pik is the proportion of land-use category j within a half-mile radius of the developed area surrounding hectare grid-cell k; j = number of land-use categories; and K = number of actively developed hectares in the tract. The mean entropy ranges between 0 (homogeneity, where all land uses are of a single type) and 1 (heterogeneity, where developed area is evenly distributed among all land-use categories). ● Vertical mixture: proportion of commercial/retail parcels with more than one land-use category on the site. ● Per developed acre intensities of land uses classified as: residential; commercial; office; industrial; institutional; parks and recreation. ● Activity center mixture: Entropy of commercial land-use categories computed across all activity centers within a zone; Proportion of activity centers with more than one category of commercial-retail uses; Proportion of activity centers with stores classified as: convenience; auto-oriented; entertainment/recreational; offices; institutional; supermarkets; service-oriented. ● Commercial intensities, measured as per developed acre rates of: convenience stores; retail services; supermarkets; eateries; entertainment and recreational uses; auto-oriented services; mixed parcels. Proximities to commercial-retail uses: ● Proportion of developed acres within 1/4 mile of: convenience store; retail-service use; (2) Proportion of residential acres within 1/4 mile of: convenience store; retail-service use.

Table 3.2 Indicator system at the time of the 3D Model's Proposal (Continued)

3D	Indicators
III. Design	● Streets: (1) Predominant pattern (e.g., regular grid, curvilinear grid) ; (2) Proportion of intersections that are: four-way (proxy of grid pattern) ; (3) Per developed acre rates of: freeway miles within or abutting tract; number of freeway under- and overpasses; number of blocks (proxy for the grain of road network) ; number of dead ends and cul-de-sacs; (4) Averages of: arterial speed limits; street widths. ● Pedestrian and cycling provisions: (1) Proportion of blocks with: sidewalks; planting strips; street trees; overhead street lights; quadrilateral (i.e., rectangular or square) shape; bicycle lanes; mid-block crossings; (2) Proportion of intersections with: signalized controls; (3) Averages of: block length; sidewalk width; distance between overhead street lights; slope; pedestrian green lights at signalized intersections; (4) Bicycle lanes per developed acre. ● Site design: proportion of commercial-retail and service parcels with: off-street parking; off-street parking between the store and curb; on-street front or side parking; on-site drive-ins or drive-throughs.

Their study utilized travel data from San Francisco, USA, in 1990, focusing on the impact of the built environment on non-work trips (especially vehicle travel distance and mode choice, which was divided into whether to use personal vehicles and whether to use single-occupant vehicles). Specifically, based on 50 residential quarters and their boundaries, the study selected indicators from three dimensions, as shown in the table. The research results support the theory of New Urbanism, which suggests that compact, diverse, and pedestrian-friendly communities can effectively reduce private car use and encourage more walking, cycling, or public transportation.

The 3D model proposed by Cervero and Kockelman suggests that through conscious design of the built environment, especially the comprehensive effects of density, land use diversity, and design, urban travel patterns can be effectively changed, reducing dependence on cars and increasing the proportion of green travel. This research provides a theoretical basis for understanding and promoting sustainable urban development and is widely applied in studies addressing the relationship between travel demand and environmental sustainability.

In fact, in the 3D "Proximities to commercial-retail uses", it is already quite close to the Distance dimension. However, it was in 2001 that Destination accessibility was officially incorporated into the D framework, becoming an important independent variable in the transportation-land use relationship, thus forming the 4D theory (Table 3.3). At that time, some of the most intractable issues—urban sprawl, traffic congestion, and air pollution—prompted an increasing number of localities and states to turn to land planning and urban design in order to reduce dependence on cars. It was urgent to mitigate travel and car demand by altering the built environment. Therefore, Ewing and Cervero synthesized over 50 empirical findings to define the 4D concept: 1) Density (population and employment per square mile); 2) Diversity (ratio of jobs to population); 3) Design (pedestrian environment variables, including street grid density, sidewalk integrity, and route directness); 4) Destination (accessibility to other activity centers, represented as the average travel time to all other destinations within the area. For example, locations within the core area of a region usually have a higher "Destination" rating than those on the edge of the city, as central locations are more accessible to a higher proportion of the region's employed population). They believed that when used for regional-scale analysis, the fourth D, accessibility, could enable the analysis to recognize the benefits of locating development projects near transportation corridors and in central locations relative to compatible activities. The calculation method for the fourth D, destination accessibility, is based on a gravity model, with regional attractiveness estimated using the total number of jobs (or attractions) within the destination area. The impact coefficients of the four Ds on land use are shown in the table, but they may vary depending on specific circumstances. The 4D has been incorporated into the Smart Growth Index (SGI) model of the Environmental Protection Agency (EPA).

Table 3.3 Degree of influence of 4D on travel

Built Environment Variables (4D)	Vehicle Trips	Vehicle Miles Traveled
Density	-0.043	-0.035
Diversity	-0.051	-0.032
Design	-0.031	-0.039
Destinations	-0.036	-0.204

The explanation for 5D is as follows:

Density is typically measured per unit area. The area can be total area or net area,

and the variable of interest can be population, residential units, employment, building area, or others. Sometimes, population and employment are added together to calculate the overall activity density per unit area.

Diversity measures involve the number of different land uses within a given area and their degree of representation in land area, building area, or employment. The entropy measure of diversity is widely used in travel studies, where low values indicate a single-use environment and high values indicate more diverse land uses. Ratios of jobs to housing or jobs to population are less commonly used.

The design encompasses the characteristics of the street network within the area. The street network ranges from dense urban grids of highly interconnected straight streets to sparse suburban networks forming loops and curved streets. Metrics include average block size, proportion of four-way intersections, and number of intersections per square mile. Design is sometimes also measured by sidewalk coverage (the proportion of the block surface with sidewalks), average building setback, average street width, pedestrian crossings, number of street trees, or other physical variables that distinguish between pedestrian-oriented environments and car-oriented environments.

Destination accessibility measures the ease of reaching a destination. It can be regional or local^[132]. In some studies, regional accessibility refers solely to the distance to the central business district. In other studies, it refers to the number of workplaces or other attractions that can be reached within a given travel time, with the highest level often found in central locations and the lowest in peripheral locations. The gravity model of travel attraction measures destination accessibility. Local accessibility differs, and Handy^[132] (1993) defines it as the distance from home to the nearest store.

The distance to transportation is typically measured as the average of the shortest street route from a residence or workplace in a certain area to the nearest railway station or bus stop. Alternatively, it can be measured in terms of bus route density, the distance between bus stops, or the number of stops per unit area.

The proponent of 5D points out that these are rough classifications with overlaps, and these boundaries may change in application. However, it is meaningful to use the D variable for empirical research.

The inspiration from this theory for this paper is that for specific areas, 5D can be used to describe the characteristics of facility layout and travel patterns. In Chapter 5 of this paper, for the areas surrounding single-type facility residential quarters-facility OD

flow clusters, the paper describes the characteristics of the region based on the "road condition" dimension of 5D, including regional facility density, regional facility diversity, regional design, and so on.

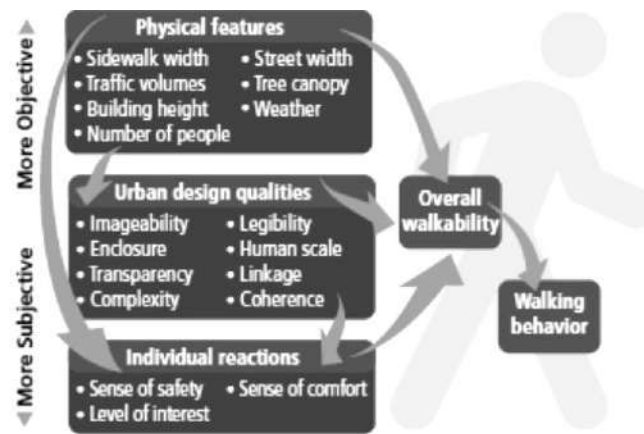
(3) **Walkable City Theory** (Pedestrian- and Transit-Oriented Design (PTOD) , Walkable City Theory)

The theory of walkable cities originates from the New Urbanism and Transit-Oriented Development (TOD) practices, systematically proposing spatial design principles that enhance the attractiveness of walking and public transportation through refined urban design, thereby reducing residents' reliance on car travel. This theory was elaborated by American urban design scholars Reid Ewing and Keith Bartholomew in their 2013 book "Pedestrian- and Transit-Oriented Design"^[133]. Based on the summary of previous pedestrian-oriented research, the book explicitly proposes eight design qualities (Urban Design Qualities) that enhance the walkability and attractiveness of cities. It argues that these eight design qualities are influenced by seven quantifiable physical characteristics, which in turn affect pedestrians' perceptions of safety, comfort, and enjoyment, ultimately influencing residents' walking choices (Figure 3.15).

The eight urban design qualities include: (a) Imageability, emphasizing that the place has distinct characteristics and clear identifiability, making it easy for residents to remember and recognize; (b) Enclosure, forming a spatial environment with clear boundaries and comfortable scales through architectural and landscape elements; (c) Human Scale, coordinating architectural and landscape design with human scale to create comfortable and pleasant activity spaces; (d) Transparency, ensuring good visual and spatial permeability between the building interface and the street, allowing street users to easily perceive internal activities and enhancing a sense of security and vitality; (e) Complexity, presenting rich and diverse details and interesting elements in urban space to stimulate explorers' desire to explore; (f) Coherence, coordinating and unifying various components of urban space visually and functionally to jointly create a harmonious and consistent street atmosphere; (g) Legibility, making the urban spatial structure clear and understandable, enabling residents to easily identify directions and navigate smoothly; (h) Linkage, ensuring efficient and safe connections between various spatial nodes in the city, ensuring convenient movement for residents in urban space. By implementing these urban design qualities, the pedestrian city theory provides clear design guidelines for optimizing urban spatial form and function, helping to shape an urban environment suitable for

walking and public transportation, and promoting sustainable urban development.

This theory's application in this research is focused on the “road conditions” dimension, where indicators related to urban design qualities are used as independent variables in Chapter 5. For instance, the street width-to-height ratio is considered, and the impact of facility-dense streets on pedestrian vitality, safety, and comfort is analyzed.



Source: Ewing and Handy 2009.

Figure 3.15 The Walkable City Theory – urban design qualities and individual perceptions framework^[133]

3.3 Cognitive framework

3.3.1 Three travel behavior sub-goals

Based on the above understanding, to explore how facility layout promotes green travel within the 15-minute cycling living circle, this study simplify question to a goal that all-type green travel, and this goal can be broken down into three sub-goals of three travel behaviors according to below analysis of Two perspectives facility travel and Two-stage processes choice (Figure 3.16).

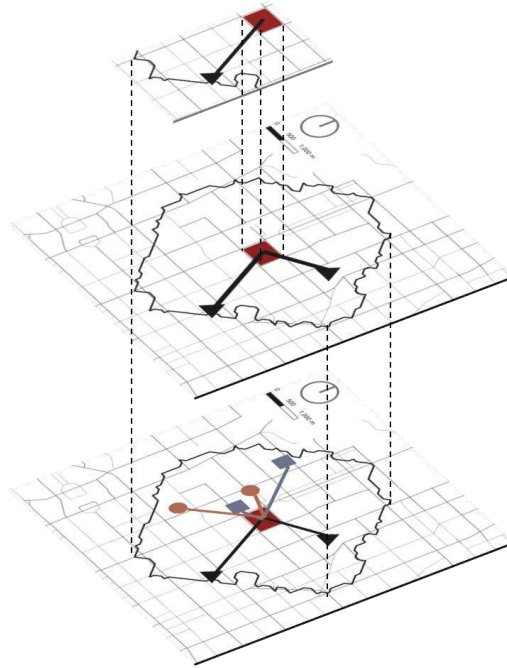


Figure 3.16 Three types of space corresponding to three travel behavior sub-goals

3.3.1.1 Two perspectives: all-type vs. single-type facility travel

Based on the theories discussed earlier, facility travel can be examined from two perspectives: **All-type** (e.g., 15-Minute City Theory) and **Single-type** (e.g., Huff Model, Living Circle Theory) (Figure 3.17).

All-type facility travel refers to all trips within the living circle. Using the living circle as a sample, this encompasses more comprehensive trips beyond the 14 facility types defined in this article. These trips are bounded by residential land and a 15-minute cycling circle, originating within the residential land and terminating within the cycling circle. This reflects residents' daily, rather than work, trips related to the 14 facility types mentioned in this article, as well as trips related to other facilities not included, such as personal errands. This comprehensive trip profile reflects the overall green travel status of the residential quarter within the living circle.

Single-type facility travel refers to trips related to a specific facility type. Using the living circle as a sample, the classification follows the 14 facility types defined in this article. Single-type facility travels are trips related to a specific facility type, bounded by residential land and a 15-minute cycling circle, originating within the residential land and terminating within the cycling circle. For example, the layout of supermarkets and trips to supermarkets reflect residents' demand for and use of these facilities.

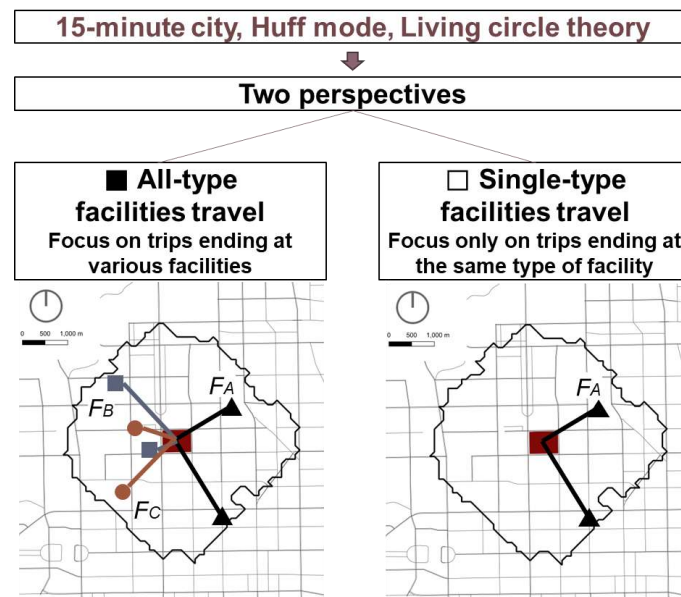


Figure 3.17 Two perspectives of facility travel

The study selected both travel at all types of facilities and travel at single-type facilities as one of the framework analysis perspectives because the overall level of green travel is closely related to the level of green travel at individual facilities. Maintaining a high level of green travel at individual facilities, especially those of high importance, can also ensure a high level of green travel at all types of facilities. For example, if one of the two living areas has a high level of green travel at each single-type facilities, the overall level of green travel at all types of facilities will also be higher.

3.3.1.2 Two-stage processes: destination choice then green travel mode choice

To achieve the goal of single-type facility green travel, the Four-Step Travel Demand Model is employed. This model breaks down travel behavior into four levels: trip occurrence, distribution, mode, and route. This framework is a classic model for macro-level motor vehicle traffic volume forecasting. While somewhat coarse-grained, it remains effective for micro-level travel characteristics within a 15-minute living area, particularly for green travel such as walking and cycling.

Drawing on the Four-Step Travel Demand Model's "second-stage distribution - third-stage mode," this thesis proposes a two-stage study of single-type facility travel: "Stage 1: Travel Destination Choice - Stage 2: Green Travel Mode Choice." Destination choice refers residents decide which facility, i.e., far but large, or near but small, will be

the destination when many facilities of the same type are available. Green mode choice refers that residents decide which mode, i.e., walk, bike, bus, car, will be taken as a destination is chosen (Figure 3.18).

So, the single-type facility travel examines the correlation between single-facility destination choice and facility layout, and the correlation between single-facility green travel mode choice and facility layout. However, in practice, the order of the two stages is reversed, as green travel is the core of the research.

Notably, the destination travel choice section is further divided into two parts: the correlation between distance choices within the 15-minute living circle and facility layout (the destination choice process), and the facility layout characteristics that influence average travel distance within the 15-minute living circle (the destination choice outcome). This thesis takes the later one—shorter average travel distance within the 15-minute living circle, i.e., avoiding single-type facility long-distance travel, as a sub-goal.

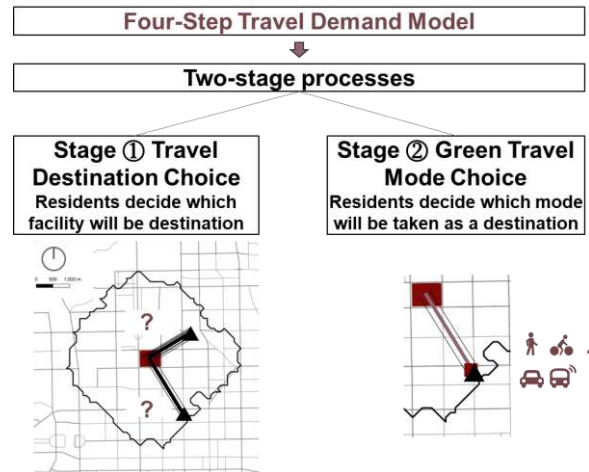


Figure 3.18 Two-stage process inspired by four-step travel mode theory

3.3.1.3 Three sub-goals integrating two perspectives and two-stage processes

Based on above Two Perspectives and Two-Stage Processes framework, the general goal all-type facility green travel can be broken down into three sub-goals (Figure 3.19): (1) encouraging all-type facility green travel, (2) avoiding single-type facility long-distance travel, and (3) encouraging single-type facility green travel. What social attributes and environmental characteristics (facility layout characteristics) will affect these sub-goals? Can they be divided into some dimensions? The following article makes

an assumption, assuming that some dimensions have a greater impact on the three goals.

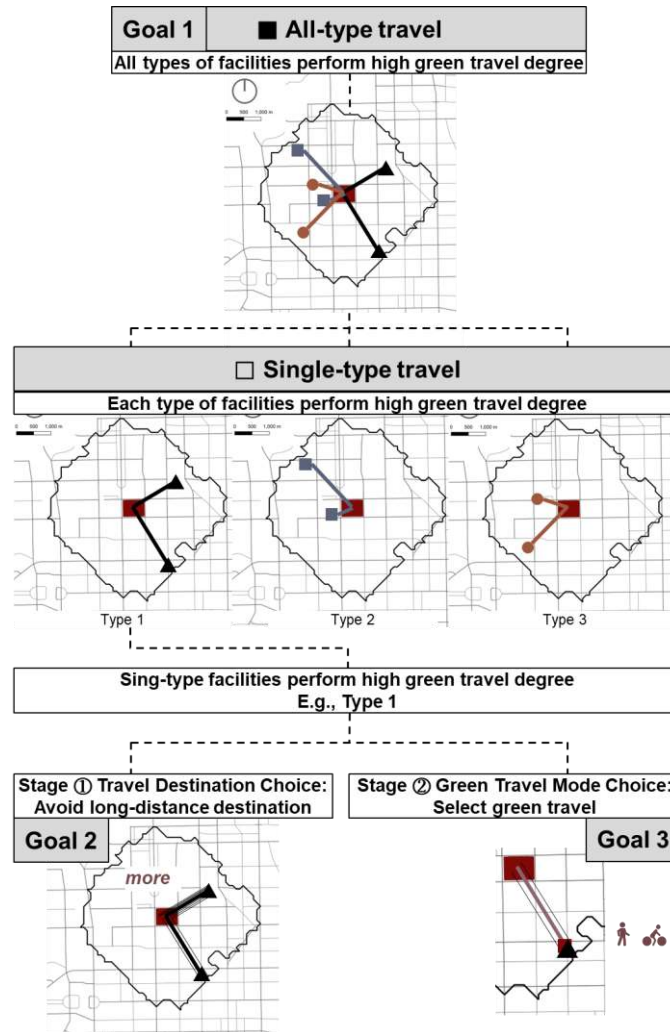


Figure 3.19 Three sub-goals

3.3.2 Six interaction dimensions of facility layout

To achieve three travel behavior sub-goals, this thesis sorts out the social attributes and environmental characteristics (facility layout characteristics) that the theory focuses on, extracting a total of six interactive dimensions, which will serve as the main dimensions for the subsequent analysis of the relationship between living circle layout and travel of three goals. Also, another auxiliary analysis dimensions two perspectives and three circles are proposed, supporting six interaction dimensions.

3.3.2.1 Six interactive dimensions: attitude, density, supply scale, diversity, distance, and road condition

Based on the two-stage travel process, we sorted out the social attributes and environmental characteristics (facility layout characteristics) that the theory focuses on, extracting a total of six interactive dimensions, which will serve as the dimensions for the subsequent analysis of the relationship between living circle layout and travel (Figure 3.20, Figure 3.21).

Dimensions affecting Green Travel Mode Choice:

For the choice of green travel (walking and cycling), the TPB provides one dimension:

- Green Travel Attitude: The residential quarter's attitude towards walking and cycling (whether green travel is considered beneficial and environmentally friendly, etc.).

The 15-Minute City Theory provides four dimensions:

- Density: The density of all types of facilities in the living area and the density of individual facilities.
- Scale: The number of city centers, usually large facilities, in the living area.
- Diversity: The diversity of all types of facilities in the living area.
- Accessibility: The proximity of all types of facilities in the living area and the proximity of individual facilities.

5D and Walkable City Theory provide one dimension:

- Road Condition: The road condition characteristics of the living area and the road condition characteristics of the OD flow cluster.

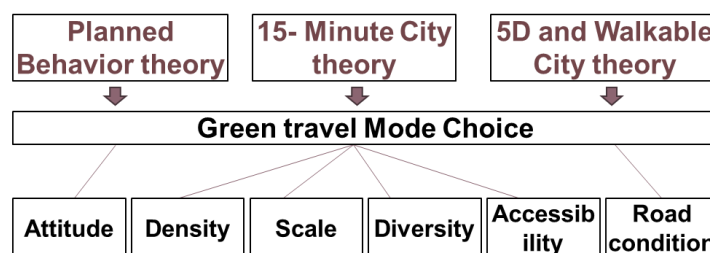


Figure 3.20 Six interaction dimensions inspired by Green Travel Choice Theory

Dimensions affecting Travel Destination Choice:

The TPB provides one dimension for travel choice:

- Travel Attitude: The attitude of the residential quarter towards long-distance

travel (whether long-distance travel is considered worthwhile, etc.).

The Huff Model provides two dimensions:

- Scale: Facility building area, etc.
- Accessibility: The distance of the facility from the residential quarter, etc.

The Living Circle Theory provides two dimensions:

- Scale: level of living center, etc.
- Accessibility: The distance of the living center from the residential quarter, etc.

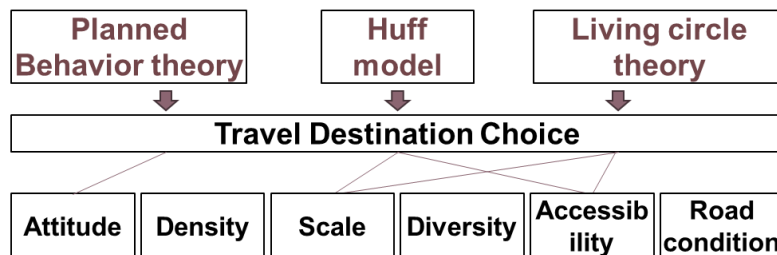


Figure 3.21 Six interaction dimensions inspired by Travel Destination Choice Theory

These six interactive dimensions constitute the core analytical dimensions of this thesis and are integrated throughout the entire empirical research.

3.3.2.2 Two perspectives: all-type vs. single-type facility layout

Based on the theories discussed earlier, this thesis proposes two perspectives, as an auxiliary dimension of the six interaction dimensions, to measure facility layout indicators. Two perspectives, in line with two perspectives of facility travel are: **all-type** (e.g., 15-Minute City Theory) and **single-type** (e.g., Huff Model, Living Circle Theory) (Figure 3.22).

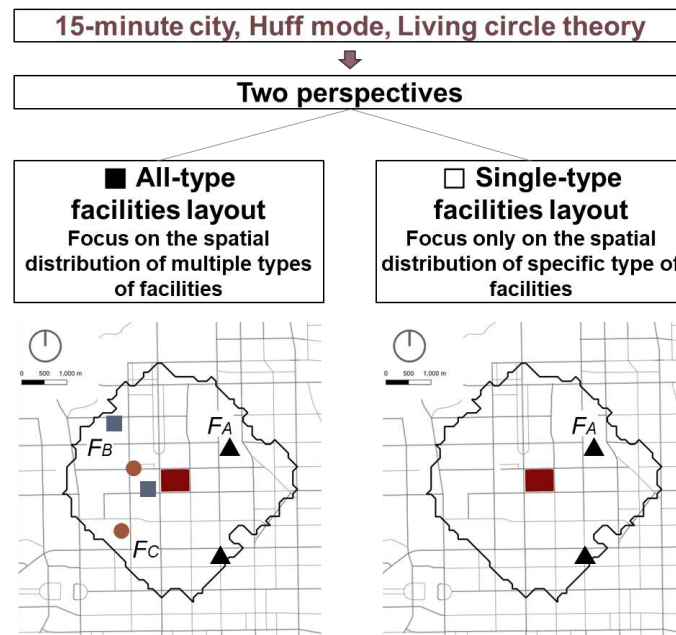


Figure 3.22 Two perspectives of facility layout

All-type Facility Layout refers to the spatial distribution of multiple facility types simultaneously, such as the characteristics of 14 facility types in thesis. Since it is impractical to account for all facilities within a living circle, this research selects 14 facility types to represent the overall layout for comparative analysis and to explore the mechanisms affecting green travel.

Single-type Facility Layout focuses only on the spatial distribution of one specific facility type, the classification comes from the 14 types of facilities, with dimensions like density and accessibility. For example, the supermarkets' density.

All-type Facility Layout provides a broader view of the overall facility layout within a living circle, while **Single-type Facility Layout** focuses on the layout characteristics of a specific facility type, offering a more granular look. By disaggregating the analysis, it is possible to identify correlations between specific facility layouts and travel behavior mechanisms, allowing for tailored strategies for optimizing facility layouts.

Beyond these two perspectives, some research in later sections will involve **Multiple-type Facility Layout** (e.g., education facilities, including primary schools, middle schools, and kindergartens, which lie between the single-type and All-type categories). According to the 15-Minute City Theory, this research identifies five **Multiple-type Facility Layout**: Shopping, Learning, Enjoying, Caring, and Traveling,

each with sub-facility types, as described in Section 1.3.4.

3.3.2.3 Three circles: residential quarters, 15-minute walking circles, and 15-minute cycling circles

The 15-Minute City Theory proposes that residents can meet their primary daily needs within a 15-minute walk or bike ride from their home. This concept provides important insights into this study's analytical framework. Building on this theory, this thesis proposes three circles, as another auxiliary dimension of the six interaction dimensions, to measure indicators such as facility density and facility diversity (Figure 3.23):

Residential Circle: This is centered around the residential quarter and serves as the spatial starting point for residents' daily travel. However, this circle is primarily characterized by social attributes, such as housing price.

15-Minute Walking Circle: This is a circle defined by the 15-minute walking distance from the residential quarter, reflecting the relationship between facility layout and travel behavior at the walking scale.

15-Minute Cycling Circle: This is a circle defined by the 15-minute cycling distance from the residential quarter, reflecting the broader relationship between facility layout and travel behavior at the cycling scale.

This hierarchical division embodies the "people-centered, family-centered" planning philosophy emphasized in the 15-minute city theory and provides a clear spatial analytical framework for further exploring how facility layout influences residents' short-distance green travel. The inclusion of the walking circle layer is due to the fact that the 15-minute cycling circle is too large, with a radius of 3 kilometers, and its facility density has little impact on green travel. In contrast, the 15-minute walking circle is relatively microscopic, with a radius of approximately 1 kilometer, and its characteristics, such as facility density, have a greater impact on green travel. Therefore, the walking circle layer is essential for the facility layout framework of the green travel living circle.

dimensions. For example, if a study requires an independent variable for "facility density," then the qualifiers must be selected from the three circles and two perspectives. If "15-minute walking circle" is selected from the three circles and "single type - primary school" is selected from the two perspectives, then the indicator would be "density of primary schools within a 15-minute walking circle."

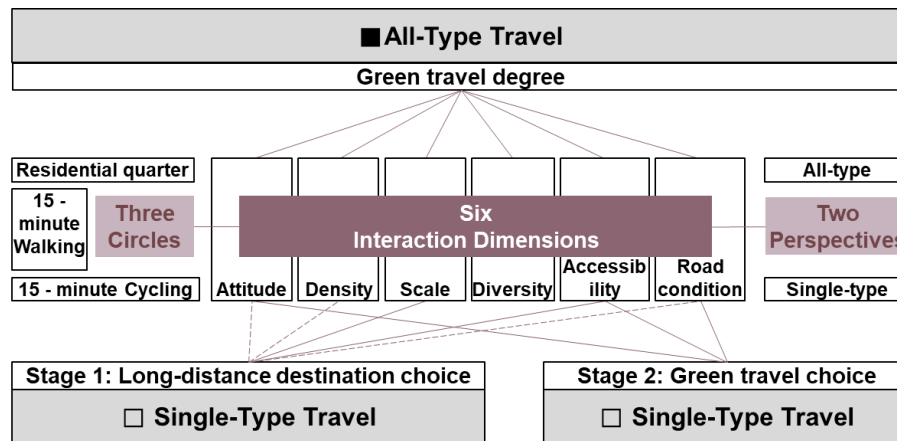


Figure 3.24 Overall analytical framework

3.4 Empirical research design

3.4.1 Analytical steps

To address the question "How can the layout of facilities in a 15-minute cycling living circle guide residents' green travel?", this study proposes a four-step detailed research process based on the three sub-goal and six interaction dimension analytical framework. Studies 1 to 3 analyze the correlations and reveal which facility layouts in the six dimensions significantly influence green travel behavior, ultimately leading to the development of optimization strategies (Figure 3.25).

- **Study 1**, corresponding to sub-goal 1, analyzes the Correlation between green travel mode choice for all-type facilities and their spatial layout. It examines 634 residential district samples, calculates the dependent variable (the green travel ratio within the living circle), describes the independent variable (facility layout features), and employs regression analysis to examine the relationship between layout and green travel. The study identifies key facility layout planning characteristics and clarifies their importance and optimal range for green travel, and cluster the living circles of different degree of green travel.

- **Study 2**, corresponding to sub-goal 2, analyzes the Correlation between green travel mode choice for single-type facilities and their spatial layout. Using over 30,000 OD flow cluster samples of 8 types of facilities within the 15-minute cycling circle of the residential district, this study calculates the dependent variable (green travel ratio of OD flow clusters), describes the independent variable (rectangular road conditions formed by the start and end points of OD flow clusters), and employs regression analysis to identify key planning features and design values corresponding to green travel, and cluster the streets of different degree of green travel.
- **Study 3**, corresponding to sub-goal 3, analyzes the Correlation between long-distance travel choice for single-type facilities and their spatial layout. The study selects 2 types of facilities and their travels in hundreds of living circles, first identifies the most important facility supply features influencing the choice of short or long-distance travel: scale (building area). Based on scale descriptions and other dimensional features, the study categorizes the facility layout features within the living circle as independent variables, calculates the dependent variable (average travel distance to singular facilities within the circle), and employs regression analysis to identify key layout characteristics, and cluster the living circles of different degree of travel distance.

Overall, the study aims to use multiple "correlation" analysis methods, integrating both "big data" and "small data", both "regression" and "clustering", to identify, classify, and examine facility layout features related to green travel at various levels. This will clarify the design thresholds for green travel in urban settings and propose typical living circles and street classifications, providing references for managers and planners to create living circles conducive to green travel.

The independent variables are detailed shown in Table 3.4, which are extracted from six interaction dimensions. For example, in study 'Correlation between green travel mode selection for single-type of facility and facility layout', the OD flow clusters' characteristics include attitude, accessibility, and road condition dimensions. In road condition dimension, mean major road length represents the average length of roads that the OD flow cluster go through.

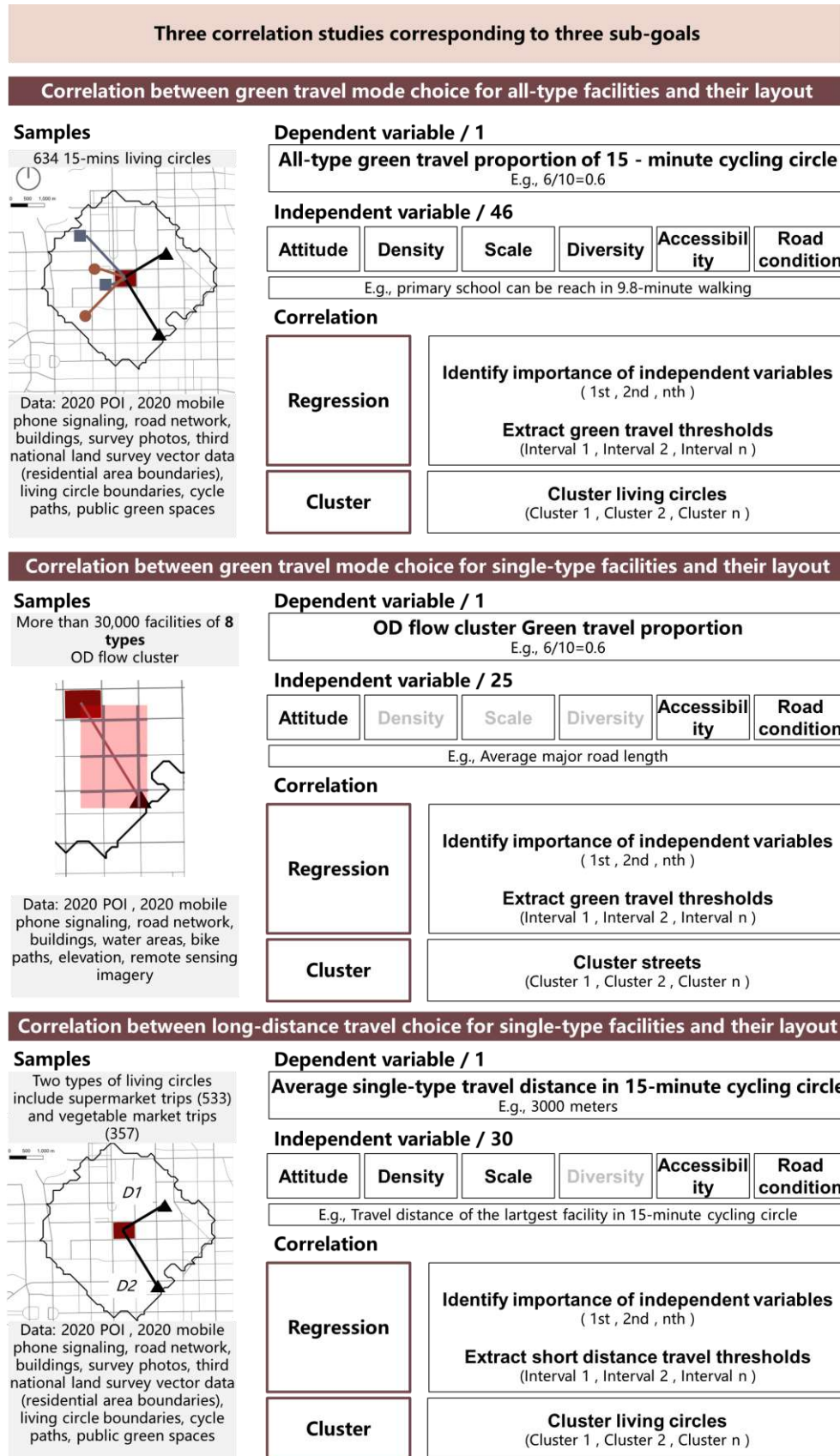


Figure 3.25 Empirical research framework

Table 3.4 Independent variables in three correlation studies

Six interaction dimensions	Correlation between green travel mode choice for all-type facilities and their spatial layout	Correlation between green travel mode choice for single-type facilities and their spatial layout	Correlation between long-distance travel choice for single-type facilities and their spatial layout
Attitude	Green travel proportion of a 15-minute cycling circle Attitude Preference Tool Ownership - Private Car Residential Classification	Attitude Tool Tool	Green travel attitude in residential quarters Car ownership rate in residential quarters Bicycle ownership rate in residential quarters Distance decay coefficient wiith city- reflects attitude preference Distance decay coefficient within 15-min cycling circle- reflects attitude preference Scale coefficient within city- reflects attitude preference Scale coefficient within 15-min cycling circle- reflects attitude preference
Density	Average building height on residential land Public green space within a 15-minute walking circle Density of single type of facilities (16) Density of 14 types of facilities		Number of supermarkets visited within 15-minute cycling circle Number of trips to the supermarket within 15-minute cycling circle Number of supermarkets visited within 15-minute walking circle Number of trips to the supermarket within 15-minute walking circle
Scale	Number of city centers within a 15-minute cycling circle		The largest supermarket visited The scale of the closest supermarket visited Average scale, the total scale of the supermarkets visited divided by the number of supermarkets visited The level of supermarket hinterland at the city level

Table 3.4 Independent variables in three correlation studies (Continued)

Six interaction dimensions	Correlation between green travel mode choice for all-type facilities and their spatial layout	Correlation between green travel mode choice for single-type facilities and their spatial layout	Correlation between long-distance travel choice for single-type facilities and their spatial layout
Diversity	Facility diversity within a 15-minute walking circle Facility diversity within a 15-minute cycling circle Completion time of residential quarter		
Accessibility	Accessibility of single type of facilities (14) Comprehensive accessibility of 14 types of facilities Area of 15- minute cycling circle	Destination accessibility	OD flow cluster distance Distance to the largest supermarket visited Distance to the nearest supermarket among visited Satisfaction, the proportion of trips in 15 cycling circles to all trips Satisfaction, that is, the proportion of supermarket trips within a 15-minute walking circle to all trips Satisfaction, that is, the ratio of supermarket trips within a 15- minute walking circle to the number of trips within a 15- minute cycling circle Average travel distance Distance from residential quarters to important commercial corridors Other 12 control variables
Road condition	Cycling path density within a 15-minute cycling circle	Design	12 indicators i.e., mean main roads length

Table 3.4 Independent variables in three correlation studies (Continued)

Six interaction dimensions	Correlation between green travel mode choice for all-type facilities and their spatial layout	Correlation between green travel mode choice for single-type facilities and their spatial layout	Correlation between long-distance travel choice for single-type facilities and their spatial layout
	Density of secondary roads within a 15-minute cycling circle	Density	6 indicators i.e., mean density of 14 types of street facilities
	Average length of main roads within a 15-minute cycling circle	Diversity	3 indicators i.e., mean street function mix
Total	46	25	30

3.4.2 Methodology

3.4.2.1 Overview of methods

(1) Spatial Interaction and Visualization Analysis

This study applies a modified Huff model of spatial interaction to model the relationship between the scale and distance of supermarkets and markets and their respective travel choices, verifying the dominant influencing factors for travel choice and predicting travel distribution. The study employs spatial visualization methods such as kernel density and quadrant analysis to verify the characteristics of living circle facility layouts, and uses residential facility-OD flow cluster visualization to confirm the differences in service ranges of facilities of varying scales.

(2) Map Navigation

This study utilizes the Gaode Map API. For specified travel modes, start points, and end points, the navigation function of Gaode Map outputs travel trajectories, times, and distances. This function is applied to identify travel modes in 20 million mobile data records and to plot 15-minute living circles. For designated points, Gaode Map's search function provides facility types, such as schools, for identifying travel destinations. These functions are implemented through Python, enabling automatic, fast, and batch processing.

(3) Statistical Analysis

Statistical analysis is used throughout the research. The primary statistical analyses include three components: Descriptive statistics, Regression, and Clustering analysis. Descriptive statistics, including box plots and histograms, to analyze the characteristics of travel and facility layout data. Other two methods will be introduced in 3.3.2.2 Main methods: Regression and Clustering.

(4) Natural language processing

In this study, natural language processing (NLP) is applied to evaluate the quality of features for various supermarkets and markets based on text data from public reviews. The analysis helps identify facility features that influence residents' green travel behavior, focusing on the facilities' characteristics as described by reviewers.

(5) Field Observations and Interviews

This study selects representative residential quarters and living circles for field observations, verifying the scientific validity of the conclusions drawn about the facility

layout features and their corresponding living circle types. The research utilizes 20,000 satisfaction survey responses from Tangshan residents in 2020, including data on residential types, green travel preferences, car ownership, etc. Additionally, the study includes online surveys and expert consultations to rank the importance of different facility types using the Analytic Hierarchy Process (AHP). Through in-depth interviews, planners' views on the concept and approach of Tangshan's living circle planning are gathered, revealing that planned living circles may not represent actual living circles. The study also explores through interviews which factors influence residents' facility and travel mode choices, providing the basis for selecting influencing indicators.

3.4.2.2 Regression and clustering as main methods

Since this study examines the correlation between facility layout and travel behavior, statistical analysis is used throughout the research. The primary statistical analyses include two components: Regression analysis and Clustering analysis. The value of a combination of two methods “Regression and Clustering” is that Regression alone can only reveal overall trends, and Clustering alone can only provide classification, combining the two can not only reveal causal mechanisms but also identify spatial patterns, ultimately supporting targeted and universal planning strategies. For example, the first study uses the XGBoost model and SHAP to analyze the relationship between facility layout and green travel proportion, then uses K-means Clustering to classify 15-min cycling living circles. Other two studies also uses optimal “Regression and Clustering” methods (Table 3.5).

(1) Regression analysis, using machine learning models like XGBoost and Random Forests, to measure the correlation between facility layout and travel behavior, identifying key layout features. Combined with the Sensitivity analysis like SHAP explanation algorithm or Partial dependence plots (PDP), these machine learning models can effectively interpret the non-linear relationships between independent and dependent variables^[136].

XGBoost: This regression model excels at handling large-sample regression problems, offering fast processing speeds^[137] and its predictive accuracy often surpasses that of linear models.

Random Forest (RF): This regression model is built on an ensemble of decision trees and is well suited for handling nonlinear relationships and high-dimensional

data[138]. It reduces the risk of overfitting by averaging across many trees, is relatively robust to noise, and often achieves higher predictive stability and accuracy compared with single decision tree models.

Sensitivity analysis helps to assess the extent to which predictors influence the dependent variable and identify the key features. Sensitivity analysis includes SHAP and PDP (partial dependence plot), can identify planning and design thresholds beneficial for green travel, providing actionable policy recommendations.

SHapley Additive exPlanations (SHAP): SHAP is used to analyze the influence patterns of independent variables on the green travel proportion and to determine the optimal facility layout thresholds for promoting green travel. The Shapley values are accurate, and this study uses them to showcase the local contributions of independent variables to the dependent variable.

The Shapley value is a method in cooperative game theory used to allocate a fair value to a collaborative outcome. It calculates the contribution made by each participant in the cooperation and is commonly used in machine learning to evaluate the contribution of features to model output. The calculation of the Shapley value is based on considering all possible combinations of features and calculating the marginal contribution of each feature to the final output under different combinations. This formula describes the calculation process of the Shapley value, and we can analyze the meaning of each term in the formula (as shown in the formula).

This method requires retraining the model on all feature subsets, where S is the set of all features. It assigns each feature an importance value, which indicates the impact of including that feature on the model's predictions. To calculate this impact, one model is trained with the feature present, and another model is trained without the feature.

Then, compare the predictions of the two models for the current input, where x_i represents the values of the input features in the set. For example, for sample 1, assuming feature 1 is 80, to understand the contribution of feature 1, first calculate the prediction value 1 for this sample (with feature 1 being 80 and other features at their original values) using the model trained with feature 1. Secondly, calculate the prediction value 1 without feature 1 (with features 2 to n at their original values) using the model trained only with features 2 to n . The SHAP value of feature 1 for sample 1 (this subset: only features 2 to n) is the difference between prediction 1 and prediction 1 without.

Since the effect of not using a certain feature depends on other features in the model,

the aforementioned differences are calculated for all possible subsets. Even for sample 1, to determine the contribution of feature 1, it is necessary to traverse all possible subsets (for example, subset features 2 to n, subset features 3 to n), and average these contribution values based on the possibility of feature 1 cooperating with different subsets to obtain the final Shapley value. The Shapley value of a feature is the average of the Shapley values for all samples.

$$\phi_i = \sum_{S \subseteq F \setminus \{i\}} \frac{|S|! (|F| - |S| - 1)!}{|F|!} [f_{S \cup \{i\}}(x_{S \cup \{i\}}) - f_S(x_S)] \quad (3-2)$$

This is the standard form of the SHAP (Shapley Value) formula, which is used to explain the marginal contribution of features in a model.

F : All feature sets;

$S \subseteq F \setminus \{i\}$: A feature subset i that does not include any features;

$f_S(x_S)$: Output of the model on the S feature subset;

$f_{S \cup \{i\}}(x_{S \cup \{i\}})$: Output of the model i with added features;

The Shapley value is calculated as the weighted average of each feature's marginal impact across all possible subsets.

Partial dependence plots (PDP): PDP are widely applied to interpret machine learning models by illustrating how the predicted outcome changes with different values of a selected feature, while holding the influence of other variables averaged out^[139]. To complement this global perspective, Individual Conditional Expectation (ICE) curves are often superimposed, which display the prediction–feature relationship at the level of each observation, with one trajectory per instance.

(2) Clustering analysis, including K-means and hierarchical clustering methods, to explore facility layout patterns corresponding to specific travel characteristics.

K-means clustering: Clustering was used to classify samples into different groups. K-means algorithm mainly includes two stages: calculating the clustering center and selecting the closest cluster for each unit according to the distance^[140].

Hierarchical clustering: The hierarchical clustering algorithm iteratively merges or splits clusters based on similarity measures, and finally generates a tree-like dendrogram that represents the nested grouping structure of the data. Compared with K-means, hierarchical clustering does not require predefining the number of clusters, can flexibly adapt to binary and categorical data, and provides a clear visualization of the clustering process through the dendrogram, which enhances interpretability and supports decisions

on the optimal number of clusters^[142].

Table 3.5 Methods used in three correlation studies

Variable application	Correlation between green travel mode choice for all-type facilities and their spatial layout	Correlation between green travel mode choice for single-type facilities and their spatial layout	Correlation between long-distance travel choice for single-type facilities and their spatial layout
Regression	XGBoost+SHA P	Random Forest+PDP	XGBoost+SHAP
Clustering	Weighted K-means cluster	Hierarchical clustering based on binary variables	Hierarchical clustering based on shape values

3.4.3 Data

3.4.3.1 Research data and application for variables

This research builds a multi-source heterogeneous data system that encompasses five key elements: facilities, travel behavior, spatial environment, population, and perception, supporting the modeling and analysis of green travel in living circles (Table 3.6). First, facility data is sourced from Gaode Map, Tangshan government departments, and Dianping, covering 16 types of facilities such as shopping, leisure, education, health, and transportation. Data collected includes latitude, longitude, category, and text information, which measures the density, accessibility, and diversity of facilities within the living circle, assisting in evaluating the service quality of malls and markets. Second, travel data includes mobile signaling data from China Unicom's Smart Footprint (2020), which contains departure/arrival points, travel time, and travel type. This data is used to identify OD flow clusters and measure the distance to green travel. Additionally, 2023 community satisfaction surveys and 2022 semi-structured interview results supplement the data, including attitudes toward travel, tool ownership, and policy awareness. Spatial environmental data integrates OpenStreetMap and third National Land Survey road network data, residential/non-residential building data, water bodies, green spaces, etc., for modeling street geometry and three-dimensional spatial features. Auxiliary data also

includes 2022 geographical cloud elevation data and NASA remote sensing imagery for slope and NDVI calculations. Furthermore, Tangshan cycling path and housing price data are collected to assess the economic properties of living circle travel structures and spatial features. The data system provides the basis for analyzing green travel behaviors and spatial correlations in living circles (Table 3.6).

Table 3.6 Summary of research data

Data	Source	Fields	Application
POIs of 14 Facility Types (Shopping, Leisure, Education, Health) (2020)	Amap, Tangshan Municipal Government Urban Renewal Platform, Tangshan 15-Minute Community Living circle Data, Tangshan Urban Physical Examination Data	Major/Medium/Minor Categories, Address Text, Latitude and Longitude, etc.	Measuring the Density, Diversity, and Accessibility of Shopping, Leisure, Education, and Health Facilities in Living circles; Road Conditions of Streets etc.
POIs of 2 Transportation Facility Types (2020)	Amap, Tangshan Municipal Government Urban Renewal Platform, Tangshan 15-Minute Community Living circle Data, Tangshan Urban Physical Examination Data	Major/Medium/Minor Categories, Address Text, Latitude and Longitude, etc.	Measuring the Density and Accessibility of Transportation Facilities in Living circles; Parking Configurations of Streets

Table 3.6 Summary of research data (Continued)

Data	Source	Fields	Application
Mobil e Signali ng Data (2020)	Unicom Smart Steps	Longitude, latitude, travel time, origin type (home, work, or visit), destination type (home, work, or visit)	Used to measure the green travel degree of living circles and OD flow clusters, and to calculate travel distances
Dianpi ng text data (2025)	Dianping	Names of reviewed supermarkets and vegetable markets, review texts since opening	Used to evaluate the quality characteristics of supermarkets and vegetable markets
Road networ k data (2020)	Open Street Map, road land use from the Third National Land Survey vector data	Length, width	Used to measure street layouts in living circles and to create street buffer analyses for road conditions
Reside ntial buildin g data (2023)	National Comprehensive Risk Database for Natural Disasters	Building name, building height, floor area	Used for 3D modeling, measuring street height-to-width ratios, residential building floor area ratios, and other planning indicators related to buildings
Non- reside ntial buildin g data (2023)	National Comprehensive Risk Database for Natural Disasters	Building name, building height, floor area, building use, building purpose	Used for 3D modeling, measuring street height-to-width ratios, non-residential building floor area ratios, and other planning indicators related to buildings; used to analyze the relationship between facility area and travel
Reside ntial AOI data (2020)	Third National Land Survey vector data	Residential code, urban/rural classification	Used as research samples and to delineate units for the 15-minute living circle
Water body AOI data (2020)	Third National Land Survey vector data	Water body code	Used to measure the current status of water bodies in OD flow clusters
Public green space AOI data (2023)	Tangshan Urban Physical Examination Data	Area	Used to measure the level of public green spaces in living circles
Bike Lane Data (2023)	Tangshan Urban Physical Examination Data	Names and lengths of urban greenways and dedicated bike lanes	Used for evaluating the configuration of bike lanes

Table 3.6 Summary of research data (Continued)

ata	Source	Fields	Application
Elevation Data (2022)	Geospatial Information Cloud	Raster elevation	Used for measuring elevation and slope
Remote Sensing Image Data (2022)	NASA	Raster wavelength	Used for measuring NDVI
Housing Price Data (2022)	Anjuke	Longitude, latitude, price per square meter	Used for assessing residential housing prices
Questionnaire Data (2023)	Tangshan Urban Physical Examination Community Satisfaction Survey Data	Over a hundred multiple-choice questions, longitude and latitude	Used for measuring residential demographics, age, health, attitudes toward green travel, and travel tool ownership
Interview Data (2022)	On-site and online interviews	Interviewee profiles, feedback information	Used for understanding the planning methods and concepts of Tangshan's 15-minute convenience living circle

In three correlation studies, above data are classified in two types of variables: dependent variables and independent variables.

Dependent variables describe travel behaviors like travel distance of certain facility and green travel proportion, so, phone data are used and their preprocessing to identify travel mode and purpose are necessary. The dependent variables' phone data and their preprocessing, mainly 'Travel mode identification' and 'Travel purpose identification', are introduced in 3.4.3.2 and their application are introduced in each chapter.

Independent variables describe six interaction dimensions' indicators like facility density and road design, so, multi-source data are used. The shared data for all three studies including residential quarter, living circle boundaries, POI facility data, building data, survey data. The exclusive data used only in one or two studies are planning data, DEM data and Dianping review data, etc.. The independent variables' data and their application are introduced in each chapter (Table 3.7).

Table 3.7 Data used in three correlation studies

Variable application		Correlation between green travel mode choice for all-type facilities and their spatial layout	Correlation between green travel mode choice for single-type facilities and their spatial layout	Correlation between long-distance travel choice for single-type facilities and their spatial layout
Dependent variable	Data preprocessing	Travel mode identification    		
	Data in this study	Travel purpose identification   		
	Data number in this study	Mobile phone data including travel mode	Mobile phone data including travel mode and travel purpose	Mobile phone data including travel purpose
Independent variable	Data in all studies	Tens of millions of trips ending in 634 living circles		
	Data in this study	Over 10,000 OD flow clusters in eight types of facilities, including supermarkets, vegetable markets, and primary schools		
Independent variable	Data in all studies	residential quarter, living circle boundaries, POI facility data, building data, survey data		
	Data in this study	residential quarter, living circle boundaries, POI facility data, building data, road data, planning data, and survey data	residential quarter, living circle boundaries, POI facility data, building data, road network data, water body data, DEM data, remote sensing imagery, and survey data.	residential quarter, living circle boundaries, POI facility data, building and land use boundary data, public review data from platforms like Dianping, survey data

3.4.3.2 Mobile data and processing for dependent variables

Given the importance and multi-chapter application of mobile signaling data in this study, especially for the dependent variables of travel distance and green travel proportion, the handling of this data is introduced here, covering: data sources, initial cleaning, travel mode identification, and travel purpose identification. All processing was done by author, some details are introduced in APPENDIX C.

(1) Travel Data Sources

The travel data comes from mobile phones in China, provided by Smart Footprint

Company, whose parent company is China Unicom. The data, collected from October 1 to 31, 2020, includes departure and arrival points (Figure 3.26), travel time, and trip type (home, work, or visit). Over 20 million data records are available from the Tangshan urban area (Figure 3.27).

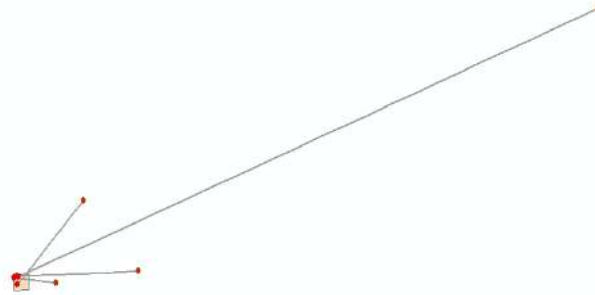


Figure 3.26 Mobile data and OD points

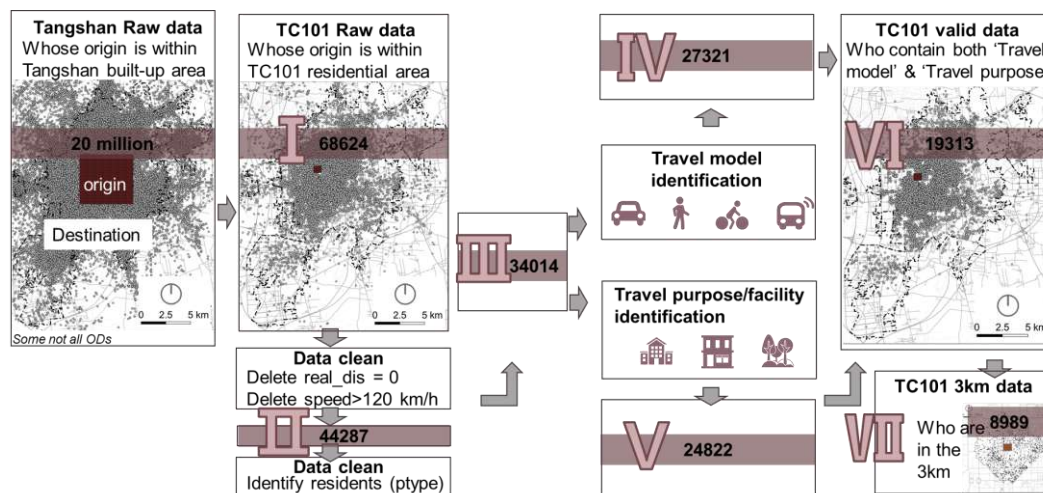


Figure 3.27 Travel data processing (Example: Tangcheng 101 residential quarter).

Source: Author's Drawing.

(2) Data Cleaning and Selection of Resident Data

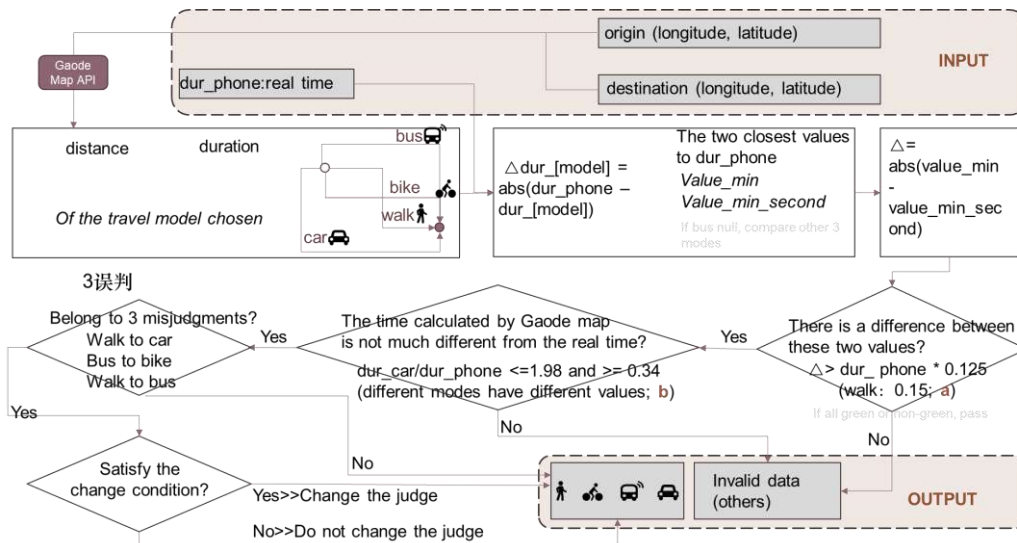
The mobile data undergoes two steps of cleaning: first, data with a haversine distance of 0 is deleted, and second, data with a speed exceeding 120 km/h is deleted due to unrealistic positioning errors caused by signal drift. The remaining data represents the travel of residents, including a total of 34,014 data points within the boundary of Tangcheng 101.

(3) Travel Mode Identification

Both the research on comprehensive green travel and individual green travel requires

travel data with specific travel modes. Therefore, the first step is to identify the travel modes in mobile phone data. Although this study focuses on two types: green travel and non-green travel, in reality, these two types, along with the commonly used travel modes of residents, encompass four types: walking, cycling, public transportation, and cars. Therefore, these four types are set as the targets for each travel data in the identification step. The core is to compare the travel time obtained from AutoNavi navigation with the time in mobile phone data representing the actual travel time. The travel mode with a time closest to the time in mobile phone data (dur_phone) is considered as the travel mode for this data. For example, if the time in mobile phone data is 10 minutes, and the route time for walking is 12 minutes, and the route time for cycling is 4 minutes, then the travel mode for this data will be judged as walking (Figure 3.28).

Here is a case study of mobile phone data, including the starting point, ending point, and duration, demonstrating the complete processing process for travel mode identification of this data. For specific details, please refer to the appendix.



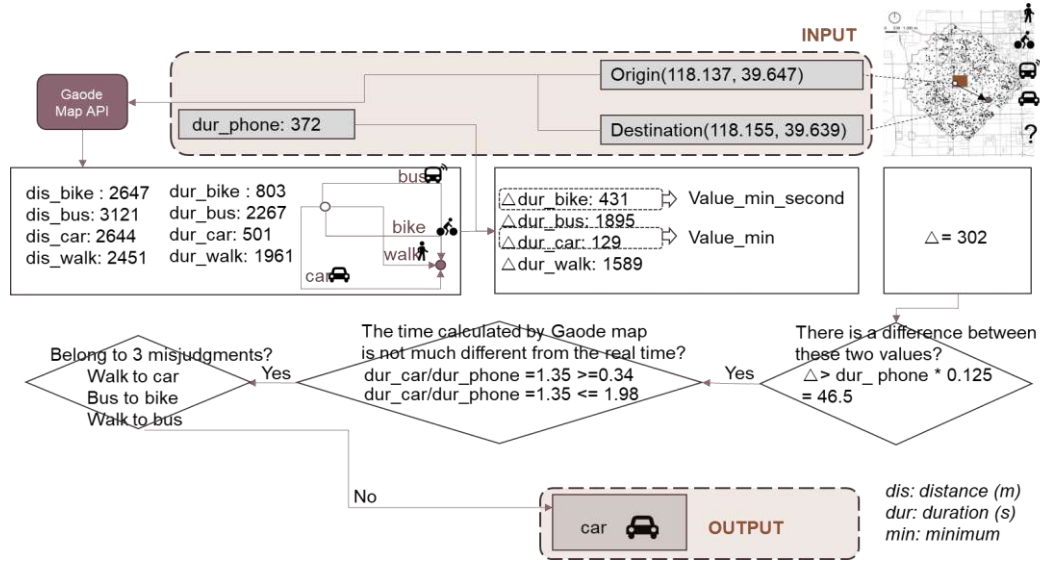


Figure 3.28 Demonstrate the recognition and processing of a segment of mobile phone data

Source: Author's Drawing.

Verification of Travel Mode Recognition Accuracy

Firstly, 8 datasets out of 4610 pieces of data were validated. For the PhD thesis on living circle, Accuracy_fuzzy_3km is meaningful, hence the accuracy range is [0.72, 0.87]. These 8 datasets differ in 3 aspects: Haversine_distance, Duration_bus, and Start_time. For the OD Haversine distance of travel data, if they cover all distances, it is denoted as (all_km); if the Haversine distance of the dataset is less than 3 kilometers, it is denoted as (3km). For Duration_bus, it indicates that the bus values obtained from Gaode Map are sometimes null. If the dataset contains null duration_bus, it is denoted as (busnull_con),

If they do not contain a null duration_bus, meaning the null duration_bus has been removed, the result is (busnull_notcon). For Start_time, it indicates whether the trip occurs during peak hours, with peak hours on weekdays being from 7:30 am to 9:00 am and from 5:00 pm to 7:00 pm. If they also include peak hours, the result is (all_time); if the dataset's start_time only includes non-peak hours, the result is (nonpeak_time). Whether the dataset's duration_bus contains a null duration_bus is more important than whether the dataset's start_time includes peak hours. The accuracy of All_km is the same as that of 3km (when the dataset's duration_bus contains a null duration_bus, i.e., busnull_con) (Table 3.8).

Table 3.8 Retention and Accuracy of grid results

Source: Summarized by the author

2789	all_k m	busnull_notc on	all_tim e	1370	3 kilome ters	busnull_notc on	all_tim e
Retained	0.71			Retained	0.74		
Accuracy	0.60			Accuracy	0.53		
Ambiguity	0.77			Ambiguity	0.72		
2095	all_k m	busnull_notc on	Off- peak hours	986	3 kilome ters	busnull_notc on	Off- peak hours
Retained	0.71			Retained	0.74		
Accuracy	0.63			Accuracy	0.54		
Ambiguity	0.81			Ambiguity	0.75		
4610	all_k m	busnull_con	all_tim e	3172	3 kilome ters	busnull_con	all_tim e
Retained	0.78			Retained	0.82		
Accuracy	0.73			Accuracy	0.74		
Ambiguity	0.85			Ambiguity	0.86		
3455	all_k m	busnull_con	Off- peak hours	2332	3 kilome ters	busnull_con	Off- peak hours
Retained	0.78			Retained	0.82		
Accuracy	0.74			Accuracy	0.75		
Ambiguity	0.87			Ambiguity	0.87		

Secondly, the verification is conducted on the mobile phone data itself. It is also based on a common sense that residents usually choose the same mode of transportation to travel from home to the same destination, especially to their workplace. Taking some residential quarters as examples, for those users who have contributed data more than twice from the same starting point and destination, we tested the proportion of travel data to travel data using the same mode of transportation and found that this proportion is as high as about 85%. Therefore, the overall accuracy of travel mode identification is proven to be around 85%.

(4) Travel purpose identification

The research on green travel with single-type facilities requires travel data with destination types. Therefore, the study conducted destination recognition on tens of

millions of travel data. Similarly, the destination of travel is identified through the Gaode Map API, relying on the platform Feature Manipulate Engine (FME). When entering the location of the destination point in FME, FME helps connect to the Gaode Map and identify the nearest POI type within a certain radius, such as a primary school. The radius here is set to 30 meters because it can maintain sufficient points and has high accuracy. Below is a case study showing its working principle (Figure 3.29).

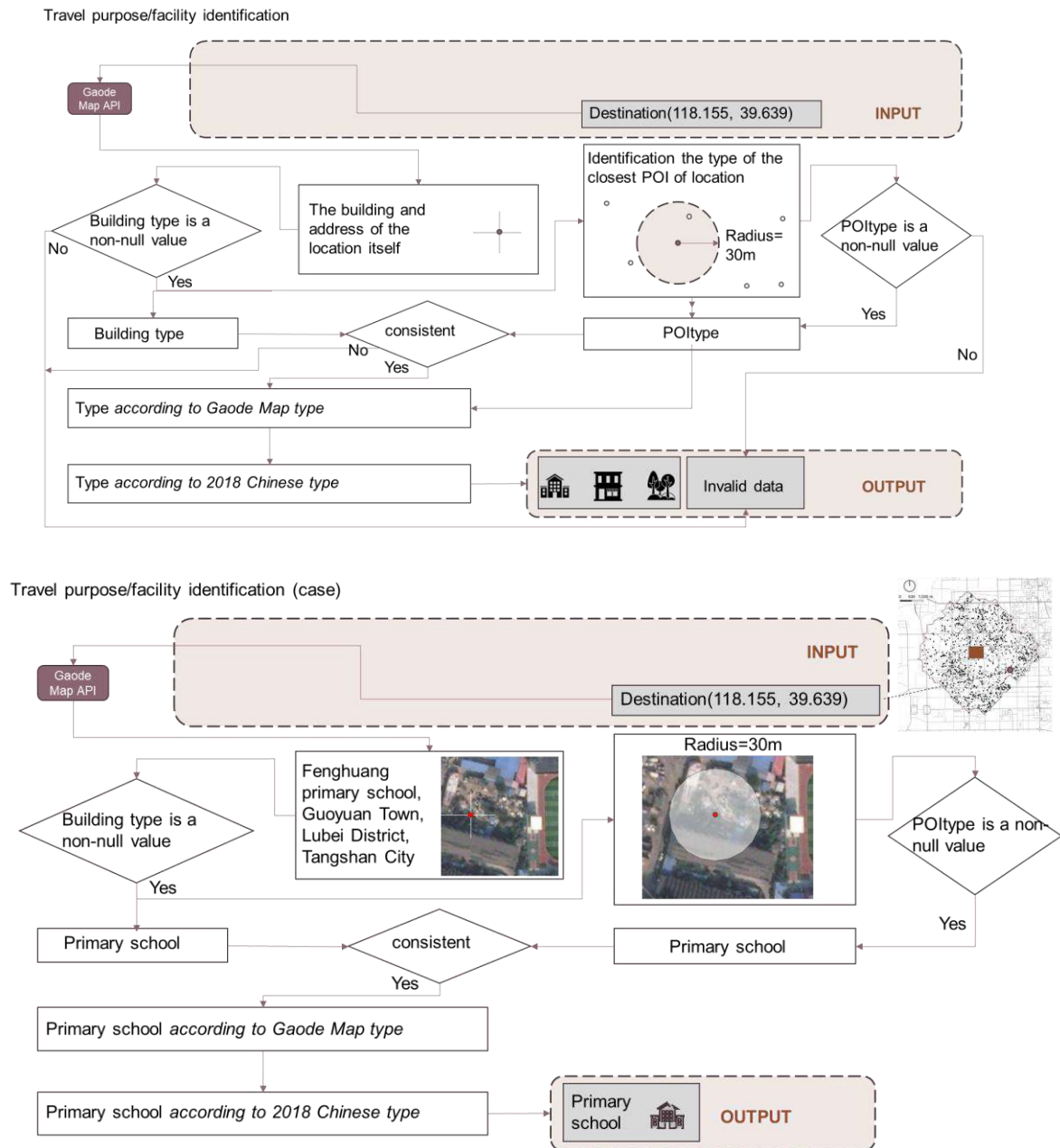


Figure 3.29 Schematic diagram of travel destination recognition

Source: Author's drawing

Since the categories returned by the aforementioned method belong to the small categories of AutoNavi Map, which are not the same as the classification used in this article, a mapping table is set up to convert "AutoNavi Map small categories" to "16 facility categories in this article" for reclassification of the returned results.

In the verification step, for POIs identified as certain types of facilities, based on the comparison of the POI spatial location with the building outline and building land outline of the facility, it was found that the POIs were basically located within the building and land outline of the facility, proving that the identification results were excellent.

3.5 Summary

This chapter found that the 15-minute cycling living circle is about 3 km in scope, and the 15-minute walking circle is about 1 km in scope. The correlation between the layout of facilities within the 15-minute cycling living circle and travel behavior is reflected in multiple levels and stages. From the perspective of all-type facility travel-single-type facility travel and the perspective of travel destination selection-green travel mode selection, the "high green travel living circle" goal is transformed into three sub-goals of travel behaviors, (1) encouraging all-type facility green travel, (2) avoiding single-type facility long-distance travel, and (3) encouraging single-type facility green travel, and therefore, based on three types of travel behavior space, three correlation analysis contents are clarified (1) Correlation between green travel mode choice for all-type facilities and their spatial layout, (2) Correlation between green travel mode choice for single-type facilities and their spatial layout, (3) Correlation between long-distance travel choice for single-type facilities and their spatial layout. Six interaction dimensions are assumed as influence factors. A key to empirical research is the selection of correlation research methods. This chapter selects "regression and clustering" as the main methods of each study. In addition, another key is the selection of data for the dependent variable travel behavior. This chapter selects mobile phone data and conducts destination identification and travel mode identification.

CHAPTER 4 CORRELATION BETWEEN ALL-TYPE GREEN TRAVEL AND FACILITY LAYOUT

The previous chapter established a theoretical framework and empirical analysis framework for correlation, including three studies. This chapter will focus on one of them: the correlation between all-type facilities green travel and facility layout, revealing the mechanisms by which the layout of facilities within 15-minute cycling living circles influences the overall green travel level within them. Using 634 15-minute cycling living circles in Tangshan's built-up area as a sample, the study integrates mobile phone, point of interest, planning, and questionnaire data. Using the green travel proportion within these 15-minute cycling living circles as the dependent variable and 46 facility layout indicators as independent variables, 'XGBoost + SHAP' is used to identify the importance and optimal ranges of layout features. Weighted K-means is then used to classify living circle types and optimize them. The conclusions identify key facility characteristics and thresholds, providing actionable empirical evidence for updating green travel orientation within living circles (Figure 4.1, Figure 4.2).

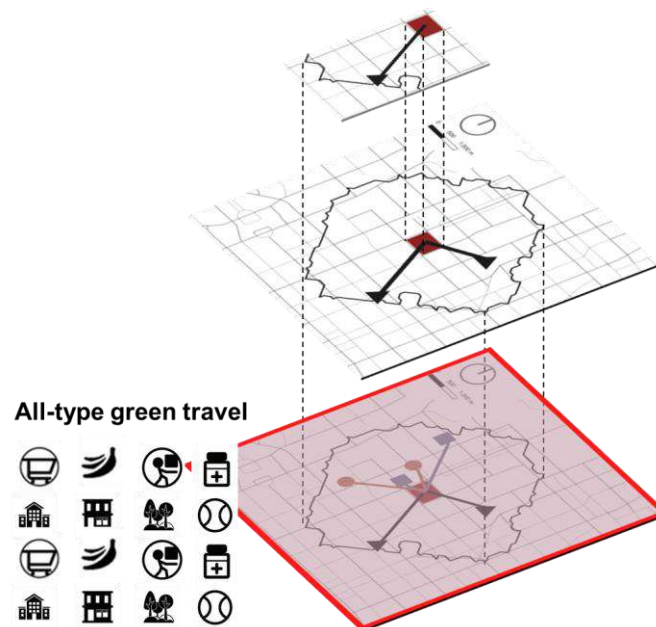


Figure 4.1 Travel behavior space of this chapter

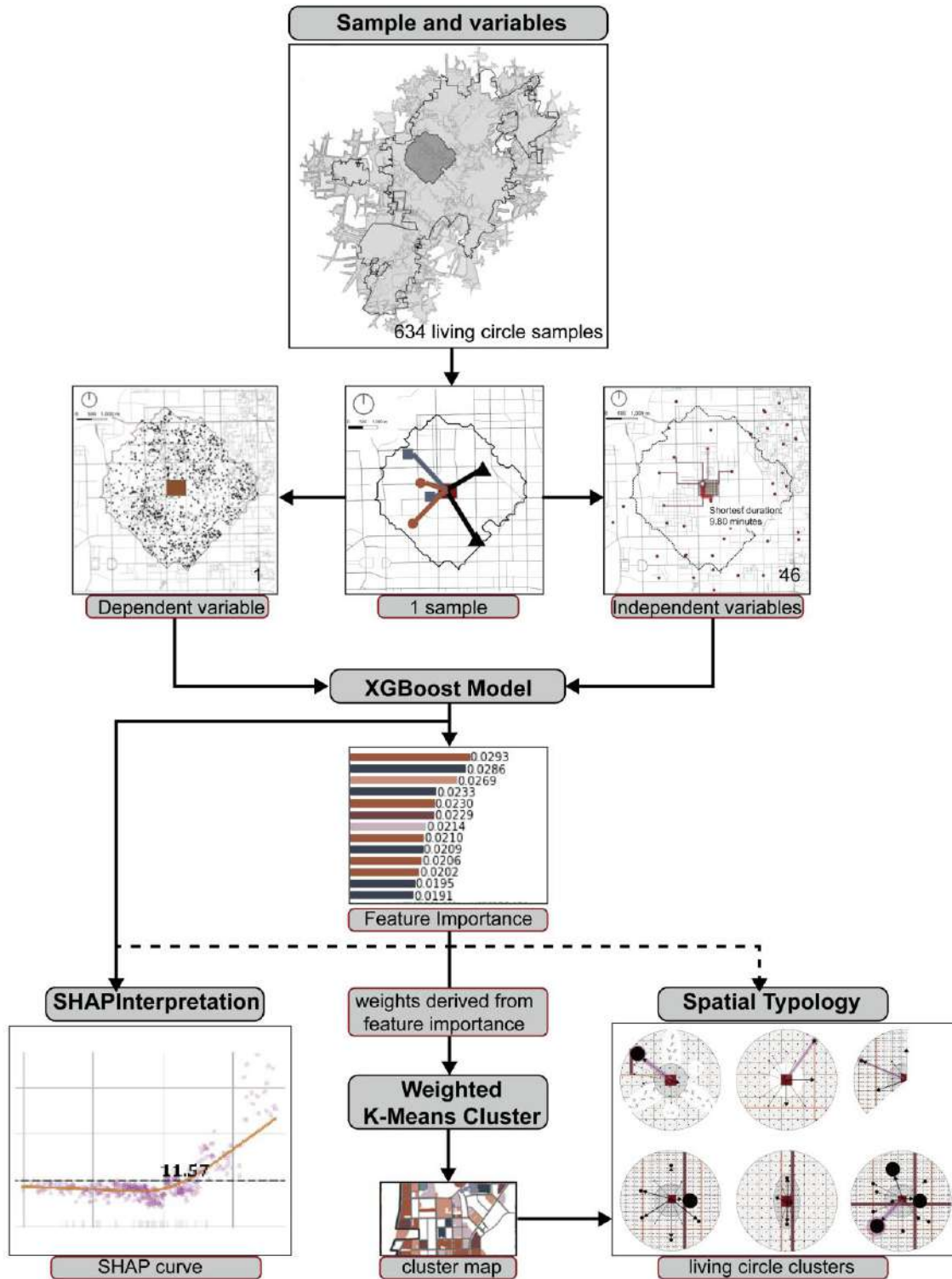


Figure 4.2 Framework of this chapter

Distinct from previous studies that typically analyze all trips—regardless of whether their destinations fall inside or outside the living circle—this research focuses exclusively on trips whose destinations are located within the living circle. By restricting the analysis to internal trips, the study is able to more accurately examine the relationship between the internal facility layout and intra-circle travel behavior, thereby providing a more precise understanding of how local spatial configurations influence green mobility.

4.1 Data, samples, and variables

4.1.1 Data: multi-source data

This chapter utilizes mobile travel data, road data, planning data, POI facility data, and survey data (Figure). Details on mobile travel data are provided in Section 3.3.3 Research Data.

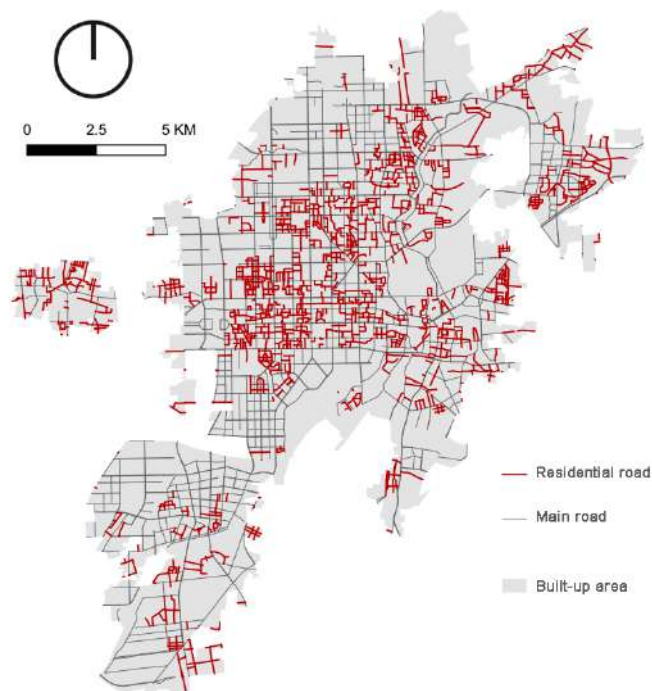


Figure 4.3 Road network data comprising main roads and residential district roads

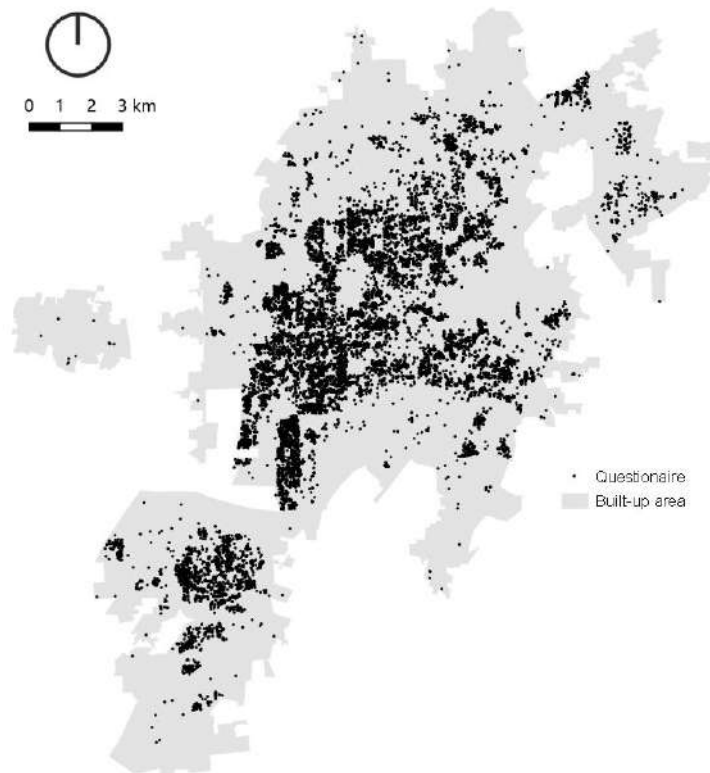


Figure 4.4 Tangshan city health check satisfaction survey data

In the built-up area of Tangshan, excluding rural residential quarters, a total of 860 urban residential quarters are selected as the research sample (Figure).

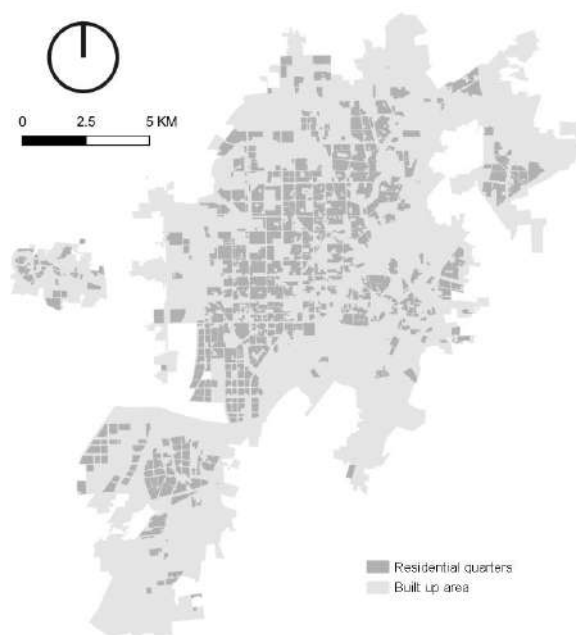


Figure 4.5 Tangshan residential quarters

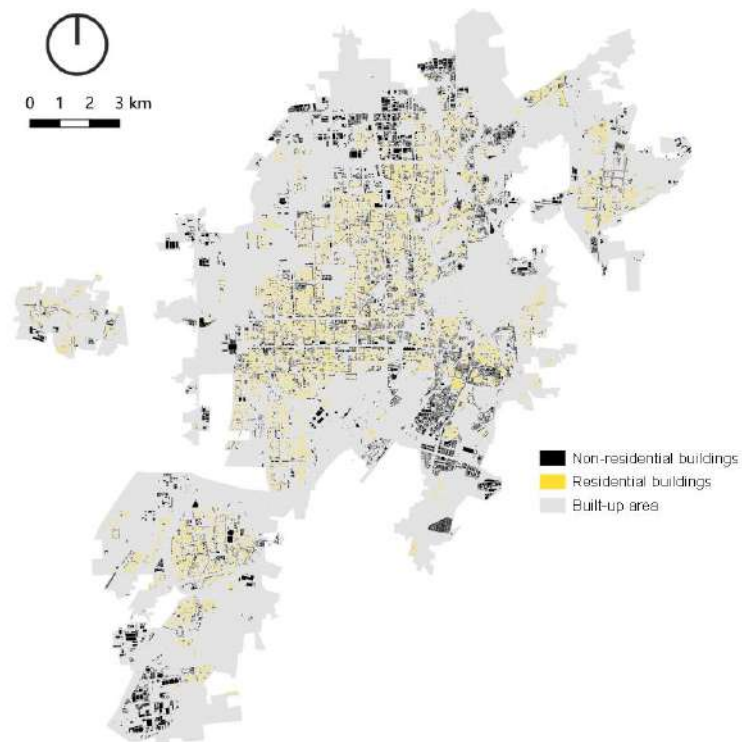


Figure 4.6 Building data comprising residential and non-residential buildings

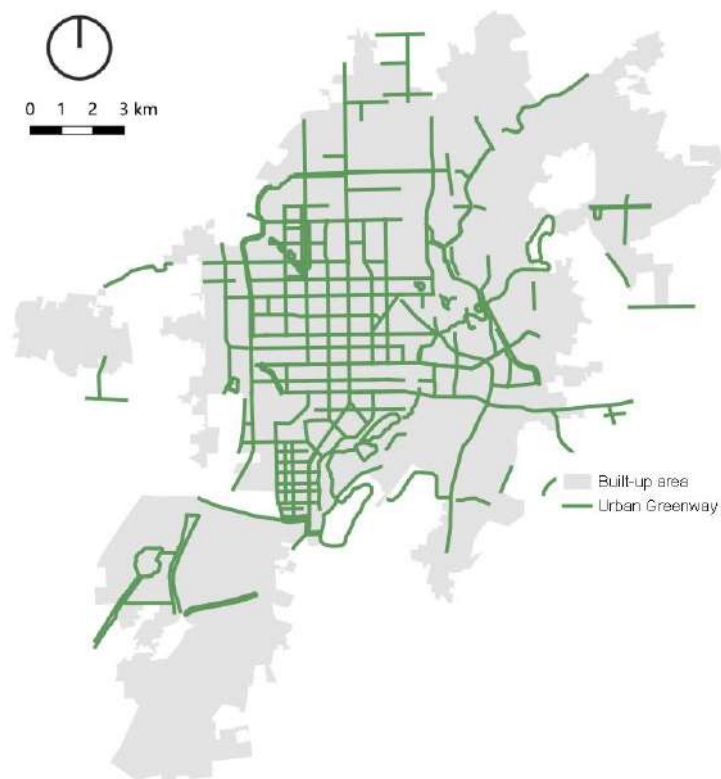


Figure 4.7 Cycling paths



Figure 4.8 City center location

The following shows the facility POI data. This study focuses on 16 types of facilities, including primary schools, middle schools, and middle schools (Figure 4.9). These facilities are essential in daily life, covering education, healthcare, commerce, and other areas. Facility data comes from multiple sources: the Tangshan Urban Renewal Data Platform, Tangshan Living Circle Planning Data, and Gaode Map POI data. Duplicate entries and naming errors were corrected for each facility type from the multi-source data.

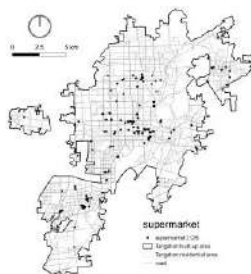


Figure supermarket (128)

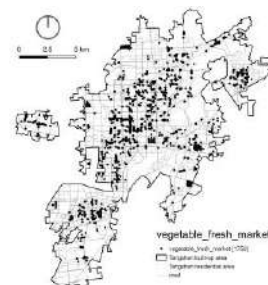


Figure vegetable_fresh_market number
(1759)

CHAPTER 4 CORRELATION BETWEEN ALL-TYPE GREEN TRAVEL AND FACILITY LAYOUT

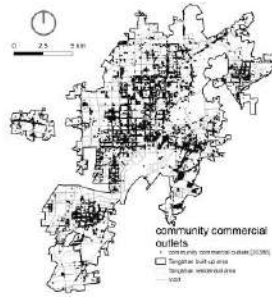


Figure community commercial outlets
(20386)

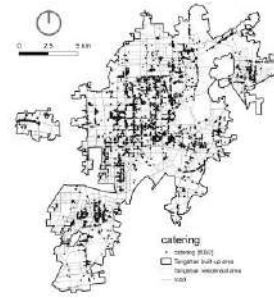


Figure catering (8092)

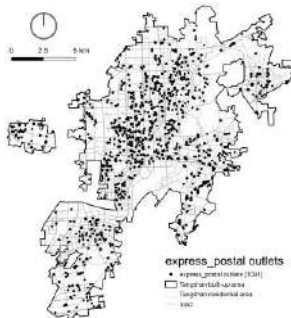


Figure express_postal outlets (1091)

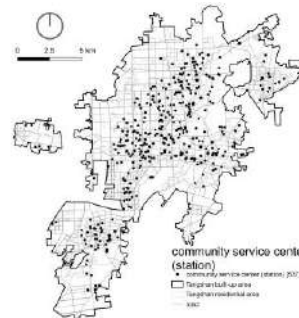


Figure community service center
(station) (537)

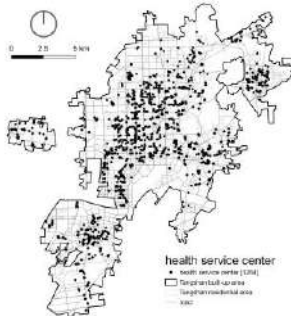


Figure health service center (1264)

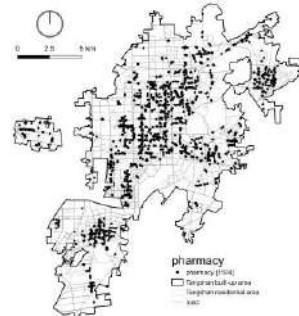


Figure pharmacy (671)

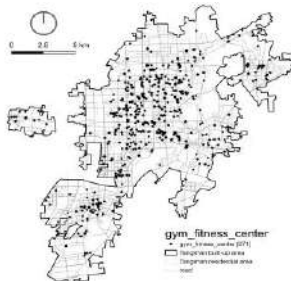


Figure sport center (gym_fitness center)
(671)

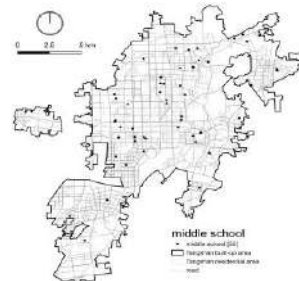


Figure middle school (middle school)
(55)

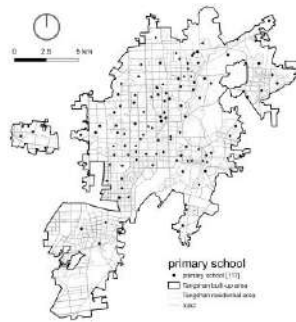


Figure primary school (117)



Figure kindergarten (214)

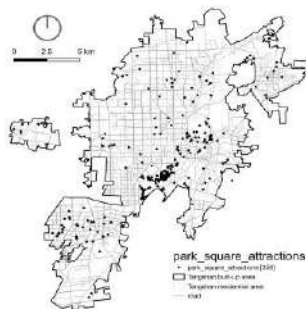


Figure park_square_attraction (356)

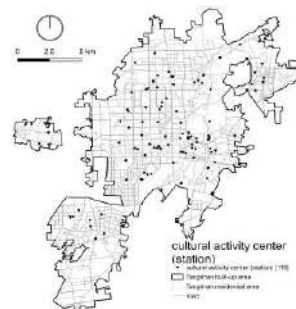


Figure cultural activity center (station)
(118)

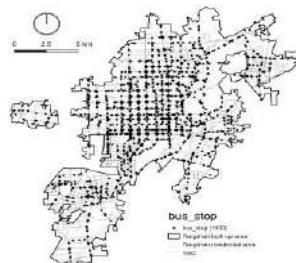


Figure bus stop (1130)

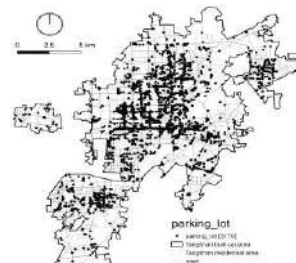


Figure parking lot (3170)

Figure 4.9 Tangshan facility POI data

4.1.2 Samples: 634 15-minute cycling living circles

The research sample consists of 634 15-minute cycling living circle samples from urban residential quarters within the built-up area of Tangshan (refer to Section 3.1.2 Method Application).

4.1.3 Dependent variable: green travel proportion of living circles

In the 860 samples, after excluding the samples with zero travel data, 634 samples

remain. The "zero travel circle" sample refers to residential quarters with no valid origin-destination (OD) records during the observation period, which are usually located in suburbs. We use the green travel ratio within the 15-minute cycling living circle as the dependent variable to measure the green travel level of the residential quarter within the 15-minute cycling circle. The green travel ratio (Green_travel_prop_life) represents the proportion of green travel (walking and cycling) in residents' daily life travel (excluding work travel). Green travel refers to walking and cycling. The ratio is calculated as the proportion of walking and cycling in all travel modes (walking, cycling, public transportation, and cars). (Figure 4.10). The origin points of trips belong to red residential quarter and inside the boundary of this quarter. The end points are inside the red residential quarter's 15-minute cycling living circle.

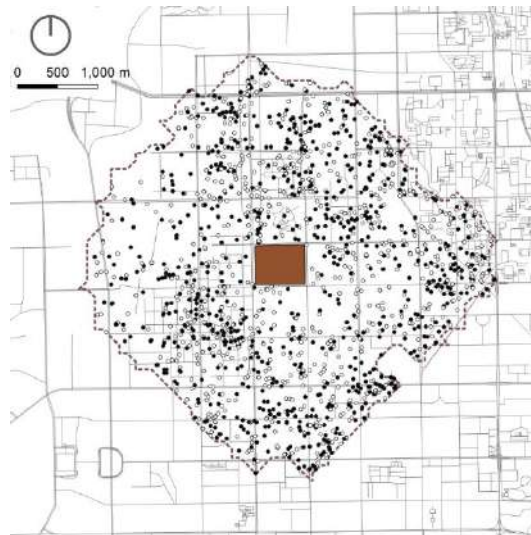


Figure 4.10 Travel and travel destinations

(Black Dots: Green Travel = Walking + Cycling; White Dots: Non-Green Travel = Public Transport + Cars).Source: Author's Drawing.

The deeper the color of an area, the higher the green travel ratio. The ratio ranges from 0-0 (lightest gray) to 0.86-1 (darkest gray). These color distinctions help visually identify areas where residents are more likely to use green travel modes such as walking or cycling. Generally, high-ratio (black) areas are mainly concentrated in the city center and some surrounding areas, possibly indicating better green travel infrastructure or stronger environmental awareness. Areas with medium ratios (gray) are more widespread, indicating a transitional status. Low-ratio areas (white) are scattered on the urban outskirts,

likely due to limited public transport or greater dependence on cars.

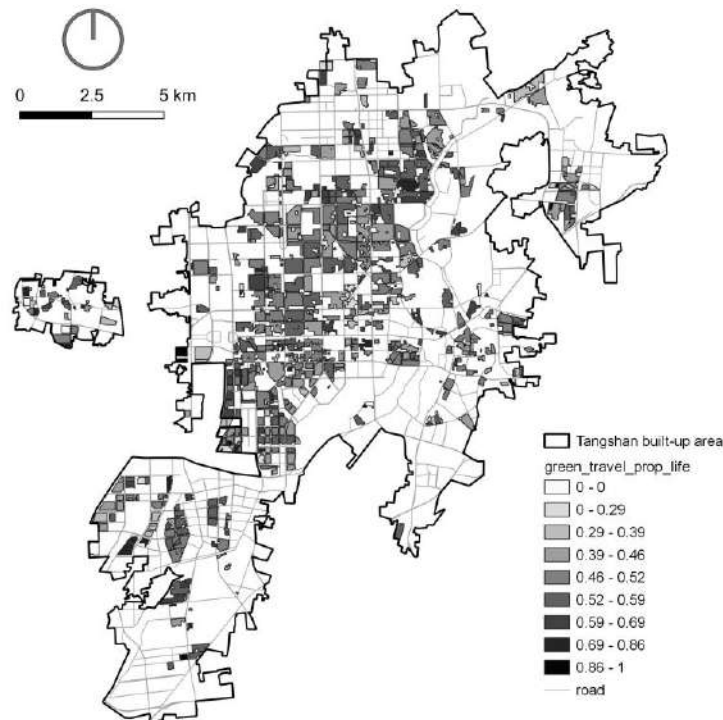


Figure 4.11 Green travel proportion in living circles

The histogram of the green travel proportion in the 634 residential samples' living circles is shown in the figure. It follows a normal distribution, with most data distributed between 0.462 and 0.528, with an average value of 0.498.

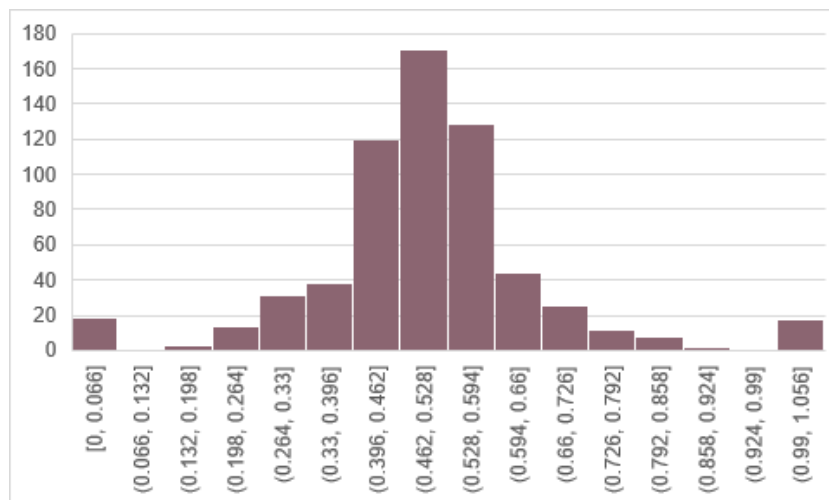


Figure 4.12 Histogram of green travel proportion in living circles

4.1.4 Independent variables: 46 facility layout indicators of living circles

4.1.4.1 Selection of variables

Based on the analysis framework, the study selects 46 indicators from three layers, six dimensions, and both comprehensive and single facility layout perspectives (Table 4.1).

Table 4.1 Independent variables and their corresponding interaction dimensions and layers

Note: R, W, and C represents Residential quarter, 15-minute walking living circle and 15-minute cycling living circle

Six interaction dimensions	Three circles	All- or single-type layout	Index	Variable name	Unit
Attitude	R	—	Green travel proportion of a 15-minute cycling circle	GTPL	none
	R	—	Attitude Preference	greprefer0	none
	R	—	Tool Ownership-private car	cartool	none
	R	—	Residential Classification	x539dui_map ped	none
	R	—	Average building height on residential land	ave_height	meter
Density	W	△ Single	Public green space within a 15-minute walking circle	pglsumw	square meters
	W	△ Single	Density of single type of facilities (16)	xxxdenw	per square kilometer
	W	▲All	Density of 14 types of facilities	number14_w_ den	per square kilometer
Scale	C	▲All	Number of city centers within a 15-minute cycling circle	nmbike10c	indivual
	W	▲All	Facility diversity within a 15-minute walking circle	diver14_w	none
Diversity	C	▲All	Facility diversity within a 15-minute cycling circle	diver14	none
Accessibility	R	—	Completion time of residential quarter	jgn_mean	year
	C	△ Single	Accessibility of single type of facilities (14)	xxx_min	minute
	C	▲All	Comprehensive accessibility of 14 types of facilities	accss14	minute
	C	—	Area of 15- minute cycling circle	area_iso	square meters
Road condition	C	—	Cycling path density within a 15-minute cycling circle	grelanden	meters per

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W	$\triangle$ Single	Density of secondary roads within a 15-minute cycling circle	rden_w	square kilometer kilometers per square kilometer
C	—	Average length of main roads within a 15-minute cycling circle	rdlemeaiso	meter

(1) Attitude

The attitude preference (greprefer0) refers to the ratio of preferred green travel modes (walking, shared bicycles, private bicycles, electric bicycles) to non-green travel modes (buses, company buses, private cars, taxis, or ride-hailing services) among residents of the residential land (unitless). This indicator reflects residents' subjective preferences for green travel modes. Data is sourced from the government's urban health check survey.

The green travel attitude (unitless) reflects the relative advantage of green travel over non-green travel, indicating residents' preference intensity for green travel over non-green travel. The specific calculation formula is as follows:

$$Attitude = \frac{Green + 0.001}{Non\sim green + 0.001} \quad (4-1)$$

Where **Green** represents green preferences, including walking, shared bicycles, private bicycles, and electric bicycles, and **Non~green** represents non-green preferences, including buses, company buses, private cars, taxis, or ride-hailing services. The small value of 0.001 avoids division by zero or extreme results. The calculation is based on the Tangshan satisfaction survey, with the survey question: "What is your main travel mode for daily commuting? Walking/shared bicycle/private bicycle/electric bicycle/motorcycle/bus/company bus/private car/taxi or ride-hailing service?" Each respondent could only select one option. Specific examples are provided: based on the geographical coordinates from the survey, the data was visualized as point data in QGIS, with 23,105 points in the built-up area; for each residential quarter, the number of points within the boundary was counted, then the green and non-green preference points were counted, and the ratio was calculated.

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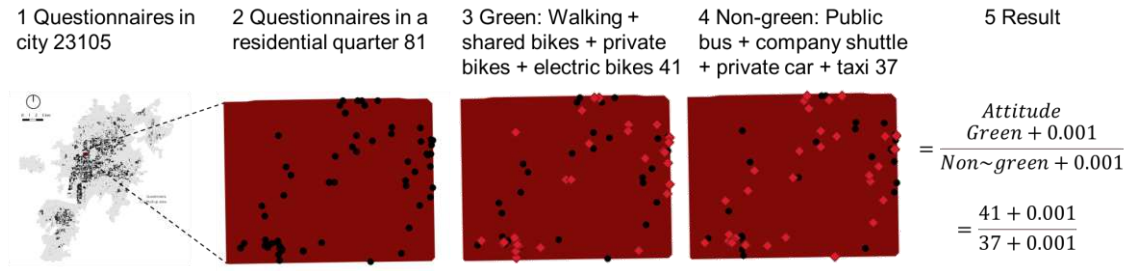


Figure 4.13 Indicator calculation based on geographic location of survey

- **Private Car Ownership (cartool)** refers to the proportion of residents with private cars to the total survey population (unitless). This indicator reflects the degree to which residents depend on private cars, which may negatively affect their willingness to use green travel modes. Data is sourced from the government's urban health check survey.

$$\text{cartool} = \frac{\text{private car}}{\text{All}} \quad (4-2)$$

- Where **private car** represents the number of private car owners, and **All** represents the total number of respondents in the residential quarter. The calculation is based on the Tangshan satisfaction survey (for details, see the Attitude indicator). The private car ownership situation was validated using the number of parking lots, proving that it reflects car ownership well.
- **Residential Classification (x539dui_mapped)** refers to the classification of residential quarter types, based on the classification standard from Tangshan's urban health check, including 6 types like commercial housing^{[147][149]}. Since this category is non-numeric, to reduce its impact on regression analysis, it is assigned a numerical value based on the average green travel ratio of each type from high to low, ranging from 1 to 6, as follows: 1. Social security housing community 2. Commercial housing community 3. Village-transformed residential quarter (e.g., urban villages) 4. Mixed 5. Work-unit-based community 6. Traditional neighborhood-type community (e.g., alleys, lanes).

(2) Density

The average height of residential buildings (ave_height) refers to the mean height (in meters) of residential buildings within the residential quarter, reflecting the floor height. High-rise buildings may be associated with high-density population, high-density facilities, and high green travel.

The density of single-type facilities within a 15-minute walking circle (xxxdenw) refers to the distribution density (units/km²) of specific types of facilities within the walking circle. The calculation method is: the number of facilities of that type within the walking circle divided by the area of the walking circle. This indicator directly reflects the level of facility supply. The higher the density, the greater the possibility for residents to meet their daily needs by walking, which promotes an increase in the proportion of green travel. The data source is POI data from the government and OSM. The specific types refer to the following 14 categories of facilities: shopping includes supermarket, vegetable, community commercial outlets, catering, express; education includes junior high school, primary school, kindergarten; health includes health service center, gym_fitness_center, pharmacy; leisure includes community service center, cultural activity center, park_square_attraction. For subcategories under each type, please refer to Section 1.3.5.

The density of 14 types of facilities within a 15-minute walking circle (number14_w_den) refers to the overall density (units/km²) of 14 types of facilities excluding bus stops and parking lots within the walking circle, calculated by dividing the total number of these 14 types of facilities by the area of the walking circle (as shown in the figure). The higher the overall facility density, the greater the satisfaction of residents' activity needs within the walking circle, which helps reduce the use of non-green travel modes^[152]. The data source is POI data from the government and OSM.

The public green space area within a 15-minute walking circle (pglsumw) refers to the total area of public green spaces (m²) within a 15-minute walking circle for daily life. The calculation method is: the sum of all public green space areas (including activity venues) within the walking circle. Green spaces can provide a comfortable and safe walking environment, increase the attractiveness of walking, and indirectly improve the proportion of residents using green transportation. The data source is the government's spatial data of urban green spaces (including activity venues). The selection is based on the "Guidelines for the Construction of Complete Residential Communities": at least one open public green space is required. Newly built residential communities should at least construct a community garden of no less than 4,000 square meters and set up 10%-15% of sports activity venues.

(3) Scale

The number of city centers within a 15-minute cycling radius (nmbike10c) refers to

the count of primary and secondary city centers located within the cycling radius (in number). Based on the primary and secondary centers identified in the overall planning of Tangshan City, and taking into account the aggregation of urban-level facilities and adjustments to hotspots based on mobile phone travel data, the primary city centers are defined as areas where multiple city-level facilities are clustered, with a total of 2 such centers. Secondary centers are locations where a single city-level or district-level facility is situated, with a total of 8 such centers. A higher number of centers within the radius indicates a higher degree of aggregation of high-level facilities, potentially enhancing the attractiveness of green travel^[146]. The data sources are government planning documents and mobile phone data (please refer to Figure attached for illustration).

(4) Diversity

The diversity of facilities within a 15-minute walking circle (diver14_w) refers to the uniformity of facility type distribution within the walking circle (no unit, as shown in the figure). The calculation method is as follows: using the entropy method to calculate the diversity index of the proportion of various types of facilities within the walking circle to the total number of facilities. The richer and more diverse the types of facilities, the easier it is for residents' diverse needs to be met within the circle, thereby increasing the use of green travel modes such as walking and cycling. The data source is POI data from the government and OSM. Drawing on the information entropy calculation method:

$$\text{facility diversity} = - \sum_{i=1}^n (p_i \times \ln p_i) \quad (4-3)$$

Among them, p_i refers to the proportion of each type of living circle facility in the overall facilities, which is the number of facility types, with each type normalized. In the formula, i "type" refers to the classification of 14 types of facilities, and "diversity" refers to the richness of these 14 types of facilities. The range of facility diversity is from 0 (low diversity) to 2.77 (high diversity).

The diversity of facilities within a 15-minute cycling circle (diver14) refers to the diversity index of facility types distributed within the cycling circle (without unit, as shown in the figure). The calculation method is similar to that of the diversity of walking circles. The higher the satisfaction of residents' needs, the more it promotes green travel. The data source is POI data from the government and OSM.

The completion time (jgn_mean) refers to the year in which the residential quarter

was completed. Residential quarters built earlier may correspond to a mature living environment and a higher level of green travel. The data comes from the Anjuke website.

(5) Accessibility

The Green Travel Proportion within a 15-Minute Walking Circle (GTPL) for residents living in residential quarters refers to the proportion of times residents within a 15-minute walking circle use walking and cycling, out of the total number of trips they make using all modes of transportation, namely walking, cycling, public transportation, and cars (without unit). GTPL can reflect the green travel characteristics of the walking circle and compensate for the limitation of the study's setting to only 16 types of real-world facilities.

The 15-minute cycling living circle area (area_iso) refers to the actual reachable area (m^2) within a 15-minute cycling distance from the centroid of residential land. The calculation method is based on map navigation, using the actual boundary of the reachable area within a 15-minute cycling distance to calculate the area. The cycling circle area reflects the spatial scale of facility distribution, and a larger area usually indicates a more dispersed distribution of facilities, which may reduce the proportion of green travel. For details of data and methods, see Chapter 4.

Single-type facility accessibility (xxx_min) refers to the average time it takes for residents to reach facilities near their residential land (Figure 4.14). For example, the accessibility of the primary school in TC101 residential land is 11.08 minutes (by walking), which means that assuming all residents of the residential land go to the primary school closest to their apartments, it takes an average of 11.08 minutes to reach it. The calculation of facility accessibility considers facilities throughout the built-up area of Tangshan City, meaning that the statistical scope is not limited to facilities within the 15-minute living circle. This is different from the statistics that only consider the quantity and diversity of facilities within the 15-minute living circle. The calculation of accessibility is based on Manhattan distance, with the specific steps as follows: First, set the starting point, draw a grid with the boundary of the residential land as the boundary, and set the distance between points as 10 meters. These points serve as hypothetical starting points, and the destination is all primary schools in Tangshan City. Next, calculate the Manhattan distance and corresponding walking time for each pair of starting and ending points (walking time is calculated based on a walking speed of 4.54 kilometers per hour, or 1.26 meters per second). For each starting and ending point, record the

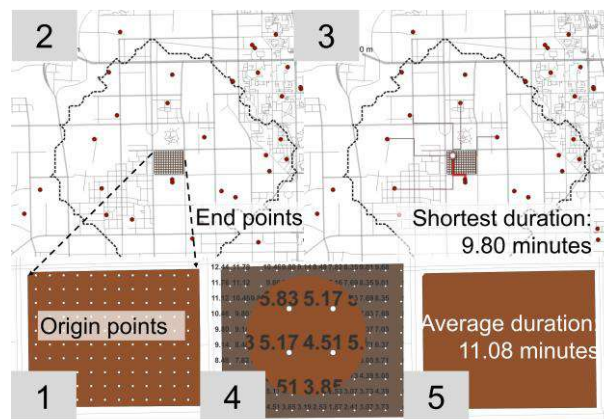


Figure 4.14 Calculation method for accessibility of facilities within a 15-minute cycling living circle in Figure Tangshan TC101 block - based on Manhattan distance calculation and taking primary schools as an example

$$\text{accss14} = \sum_{i=1}^n (\text{facility accessibility}_i \times \text{weight}_i) \quad (4-4)$$

(6) Road condition

The density of cycling lanes within a 15-minute cycling radius (grelden) refers to the density (m/km^2) of dedicated cycling lanes within a 15-minute cycling radius. It is calculated by dividing the total length of dedicated cycling lanes within the radius by the area of the radius. A higher density of cycling lanes indicates a well-developed cycling infrastructure and a tendency for residents to use green transportation modes^{[150][151]}. The data source is government urban health check data.

The average road length of main roads within a 15-minute cycling radius (rdlemeaiso) refers to the average segment length of main roads within the cycling radius (m). The calculation method is as follows: divide the total length of main roads within the cycling radius (including OSM data types such as primary, secondary, tertiary, and track) by the number of main road segments. A shorter average road length indicates a smaller block scale, facilitating walking and cycling, and promoting green travel. The data source is the OSM road network.

The density of secondary roads within a 15-minute walking circle (rden_w) refers to the density of the secondary road network within a 15-minute walking radius (km/km^2). It is calculated by dividing the total length of residential-level roads within the walking circle by the area of the 15-minute walking radius. A high density of secondary roads indicates strong accessibility for walking, facilitating green travel. The data is sourced from the OSM road network.

4.1.4.2 Measurement of variables: spatial differentiation and inter-type differences of facility density, accessibility, and diversity

The study presents the measurement results of facility density, facility accessibility, and facility diversity. Due to the overlap of the 15-minute cycling circles of the samples, the sample results are linked to residential quarters to avoid overlap, and the above three layout characteristics within the 15-minute living circle of residential quarters are displayed.

A detailed descriptive analysis was conducted on facility density, facility accessibility, and facility diversity. The distribution characteristics of sample values were represented using box plots (Figure 4.15). In the graphs and tables (Table 4.2), q0, q25, q50, q75, and q100 represent the minimum, first quartile (25% quantile), median (50% quantile), third quartile (75% quantile), and maximum values of all living circle samples,

respectively. These five quantiles constitute the upper and lower whiskers, box boundaries, and centerline of the box plot, which are used to describe the central tendency and distribution range of the variable. For the description of other independent variables (mainly mean values), please refer to Table 4.8 in Section 4.4.3.

Overall, there are significant differences in the results of the three facility layout indicators. Among them, facility density and facility diversity exhibit opposite characteristics: the density of living circle facilities on residential land decreases from the city center to the suburbs, while facility diversity shows the opposite trend (Figure).

The value range of "Comprehensive Accessibility of 14 Types of Facilities (acess14)" is 2.82-34.93 minutes. According to the box plot, the quantile values and the median of 6.86 are more biased towards the Q0 quantile, indicating a long-tailed distribution. Unlike "Facility Density", "Facility Accessibility" exhibits a multi-centered feature: Tangshan has multiple centers with high comprehensive accessibility, and most residential land shows high facility accessibility, with surrounding areas accessible within 18.8 minutes. The accessibility of residential land in the old urban area near Yuanyang City in the northeast of Tangshan is better than that in the new districts in the east and west.

The range of "total density of 14 types of facilities (number14_w_den)" is from 0.82 to 926.54, with a median of 280.44 per square kilometer, indicating an increasing density from the suburbs to the city center. This is because the population density is higher in the city center, leading to a more concentrated distribution of facilities.

The value range for "diver14_w" (diversity of 14 types of facilities within walking circle) is 0-1.82, while the value range for "diver14" (diversity of 14 types of facilities within cycling circle) is 0.98-1.7. The results deviate somewhat from our common sense, as diversity decreases from the suburbs to the city center. In the suburbs, some areas resemble small cities, where different types of facilities are located close to each other, with no one function clearly dominating. In the city center, certain specific types of functions are concentrated in these areas. Especially commercial facilities and dining facilities, which are numerous, lead to lower diversity.

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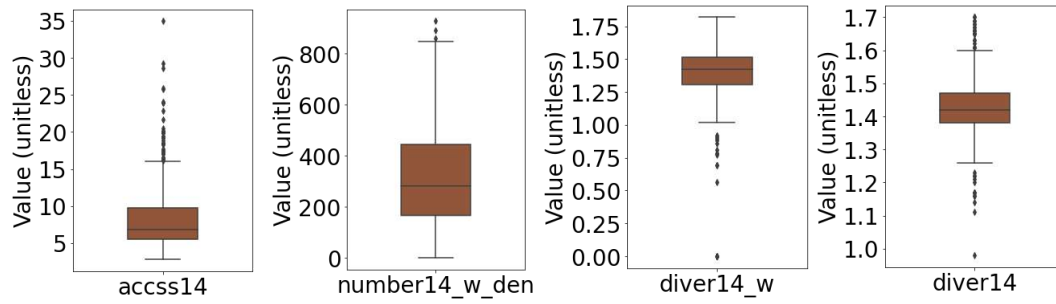


Figure 4.15 Box plots of total density of 14 types of facilities, comprehensive accessibility of 14 types of facilities, diversity of 14 types of facilities within walking radius, and diversity of 14 types of facilities within cycling radius

Table 4.2 Percentile values of total density, comprehensive accessibility, and diversity for the 14 facility types

	q0	q25	q50	q75	q100
accss14 (minutes by walk)	2.82	5.53	6.86	9.77	34.93
number14_w_den (/km ²)	0.82	166.56	280.44	442.86	926.54
diver14_w (No unit)	0	1.31	1.42	1.51	1.82
diver14 (No unit)	0.98	1.38	1.42	1.47	1.7

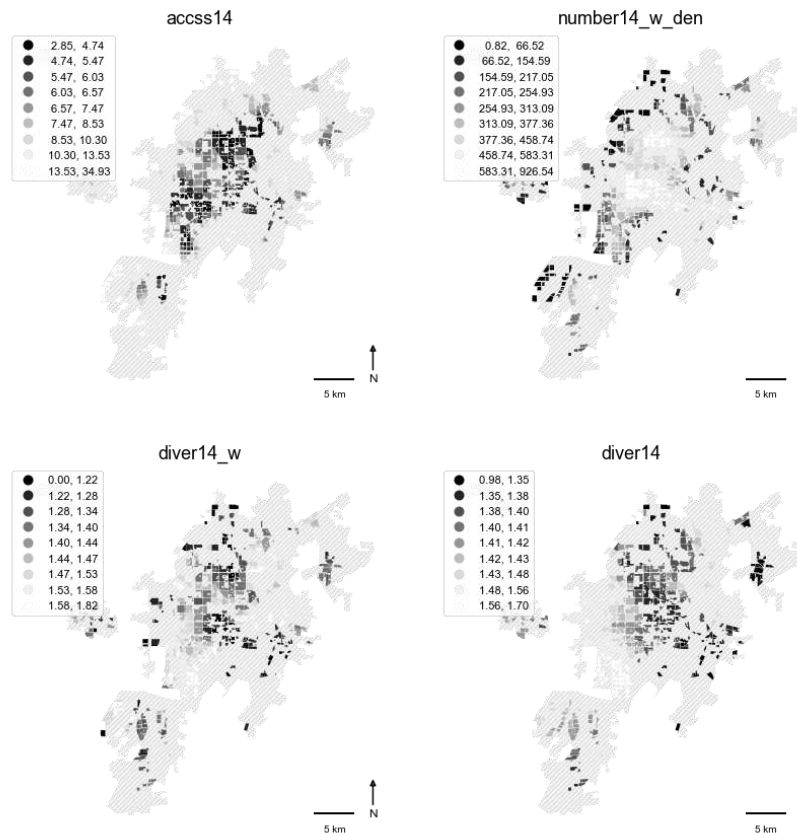


Figure 4.16 Measurement results of total density of 14 types of facilities, comprehensive

accessibility of 14 types of facilities, diversity of 14 types of facilities within walking circle, and
diversity of 14 types of facilities within cycling circle

There are significant differences in accessibility among different types of facilities (Figure 4.17, Table 4.3). Firstly, high accessibility values not only occur in downtown areas but also manifest in localized areas where specific facilities are densely distributed. Specifically, if residential land is close to certain types of facilities, its corresponding accessibility value will increase significantly. Secondly, from the perspective of facility types, the accessibility of six types of facilities, namely educational facilities, supermarkets, cultural activity centers, and parks, is generally lower than that of the other ten types of facilities (such as community commercial outlets). The walking accessibility time range for middle schools ('mid_min') is 1.24 – 50.13 minutes, with a median of 13.83 minutes, while the accessibility range for community commercial outlets ('cmol_min') is 0.16 – 19.36 minutes, with a median of only 1.12 minutes. This difference reflects the uneven distribution density of facilities themselves. For example, there are only 55 middle schools in the built-up area, but there are more than 20,000 community commercial outlets. Thirdly, combining the box plot with the statistical data of each quartile can further reveal the distribution structure of facility accessibility. For example, the walking accessibility time for supermarkets ('super_min') varies significantly across different living circles, with quartile values ranging from 5.94 minutes (Q1) to 17.07 minutes (Q3), and the maximum value (Q100) reaching 81.05 minutes, indicating that some residential quarters still face the problem of having to travel extremely long distances to obtain services. Overall, the Q1 – Q3 interval depicted by the box plot characterizes the typical accessibility situation of most residents, while the maximum value indicates potential imbalances in facility layout.

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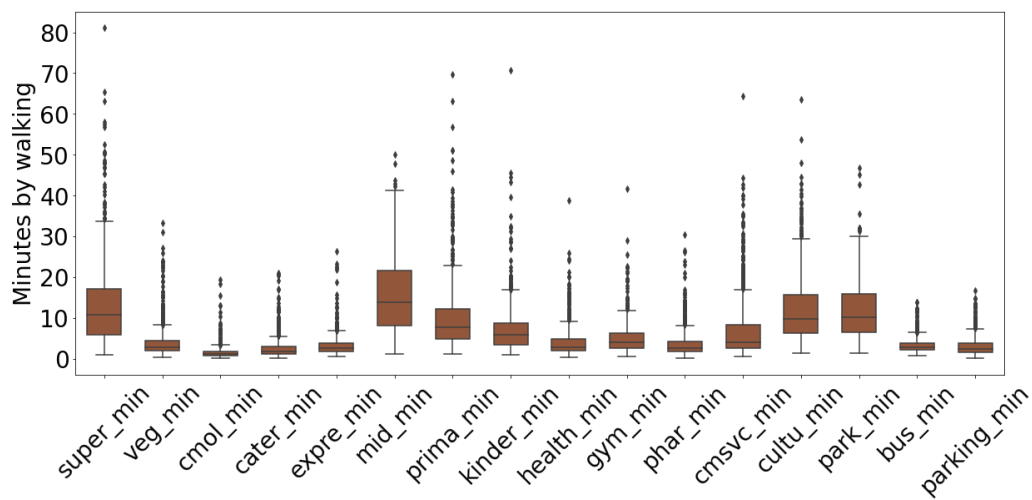
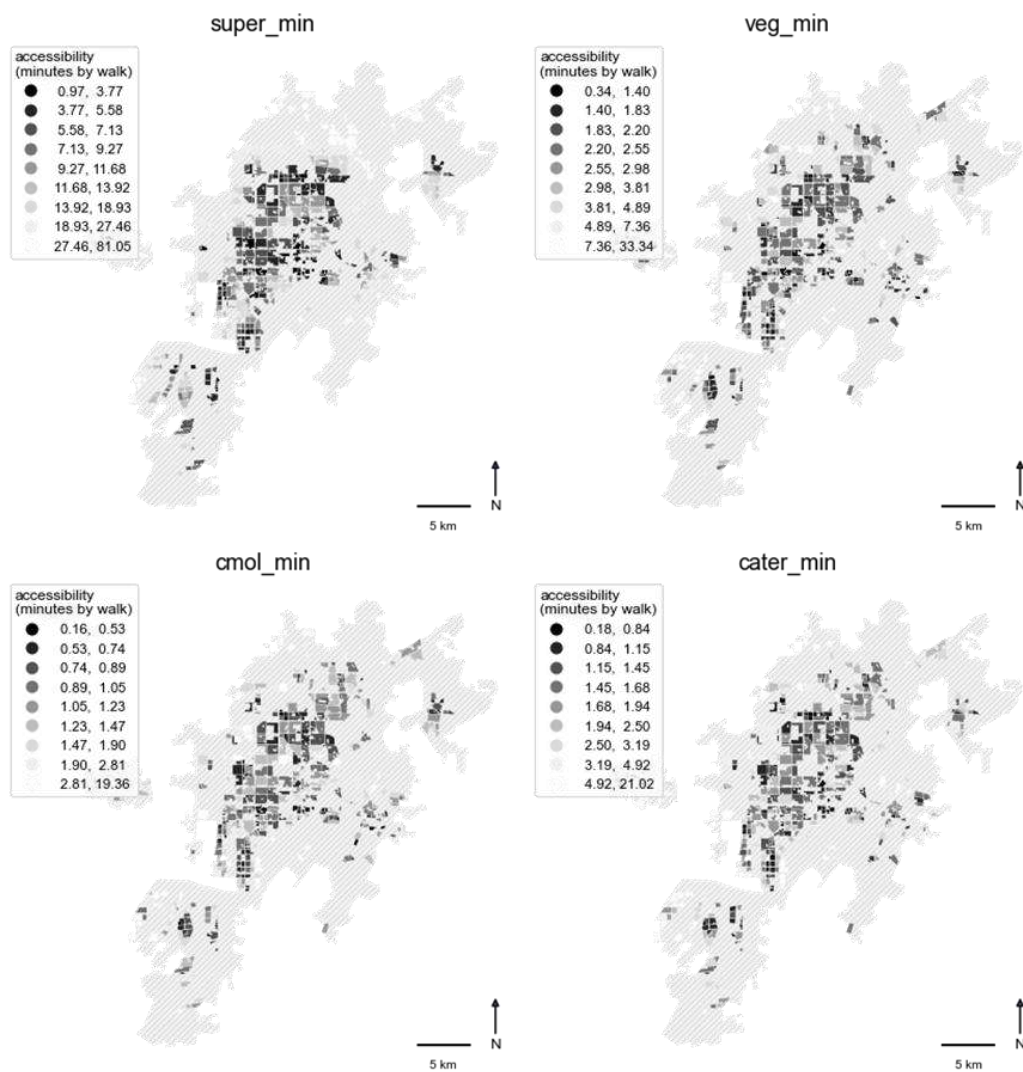


Figure 4.17 Boxplot of accessibility of single-type facilities

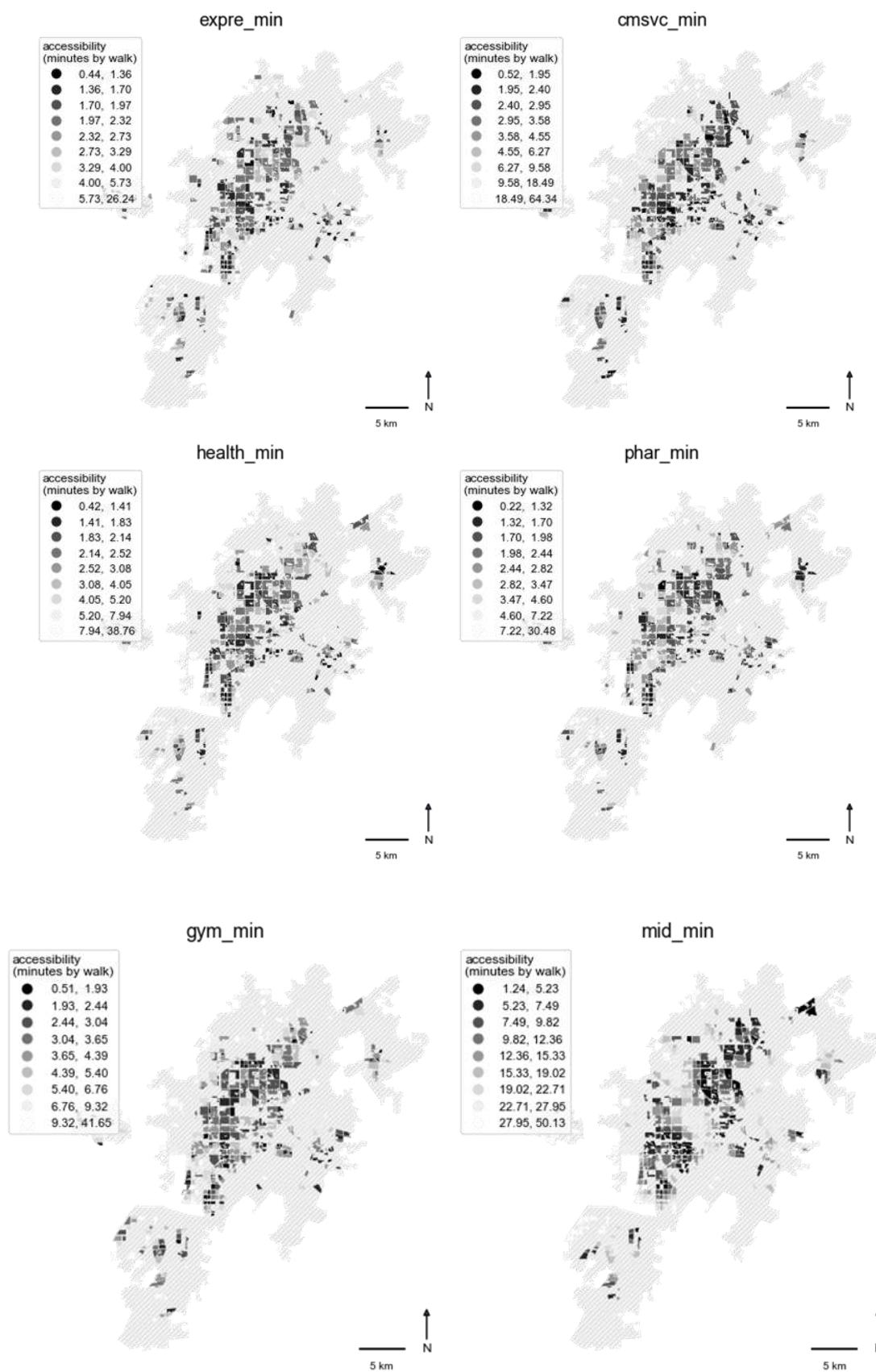
Table 4.3 Minimum, maximum, and percentile statistics for accessibility of individual facility types

Minutes by walk	Indicator	q0	q25	q50	q75	q100
Shopping	super_min	0.97	5.94	10.69	17.07	81.05
Shopping	veg_min	0.34	1.95	2.77	4.51	33.34
Shopping	cmol_min	0.16	0.77	1.12	1.8	19.36
Shopping	cater_min	0.18	1.22	1.81	2.95	21.02
Shopping	expre_min	0.44	1.79	2.49	3.83	26.24
Learning	mid_min	1.24	8.06	13.83	21.58	50.13
Learning	prima_min	1.06	4.84	7.66	12.13	69.71
Learning	kinder_min	0.96	3.39	5.9	8.79	70.68
Caring	health_min	0.42	1.92	2.72	4.92	38.76
Caring	gym_min	0.51	2.56	4.05	6.34	41.65
Caring	phar_min	0.22	1.77	2.61	4.29	30.48
Enjoying	cmsvc_min	0.52	2.48	4.01	8.32	64.34
Enjoying	cultu_min	1.44	6.24	9.74	15.64	63.57
Enjoying	park_min	1.29	6.4	10.16	15.89	46.71
—	bus_min	0.72	2.23	2.77	3.9	13.84
—	parking_min	0.2	1.48	2.29	3.85	16.62

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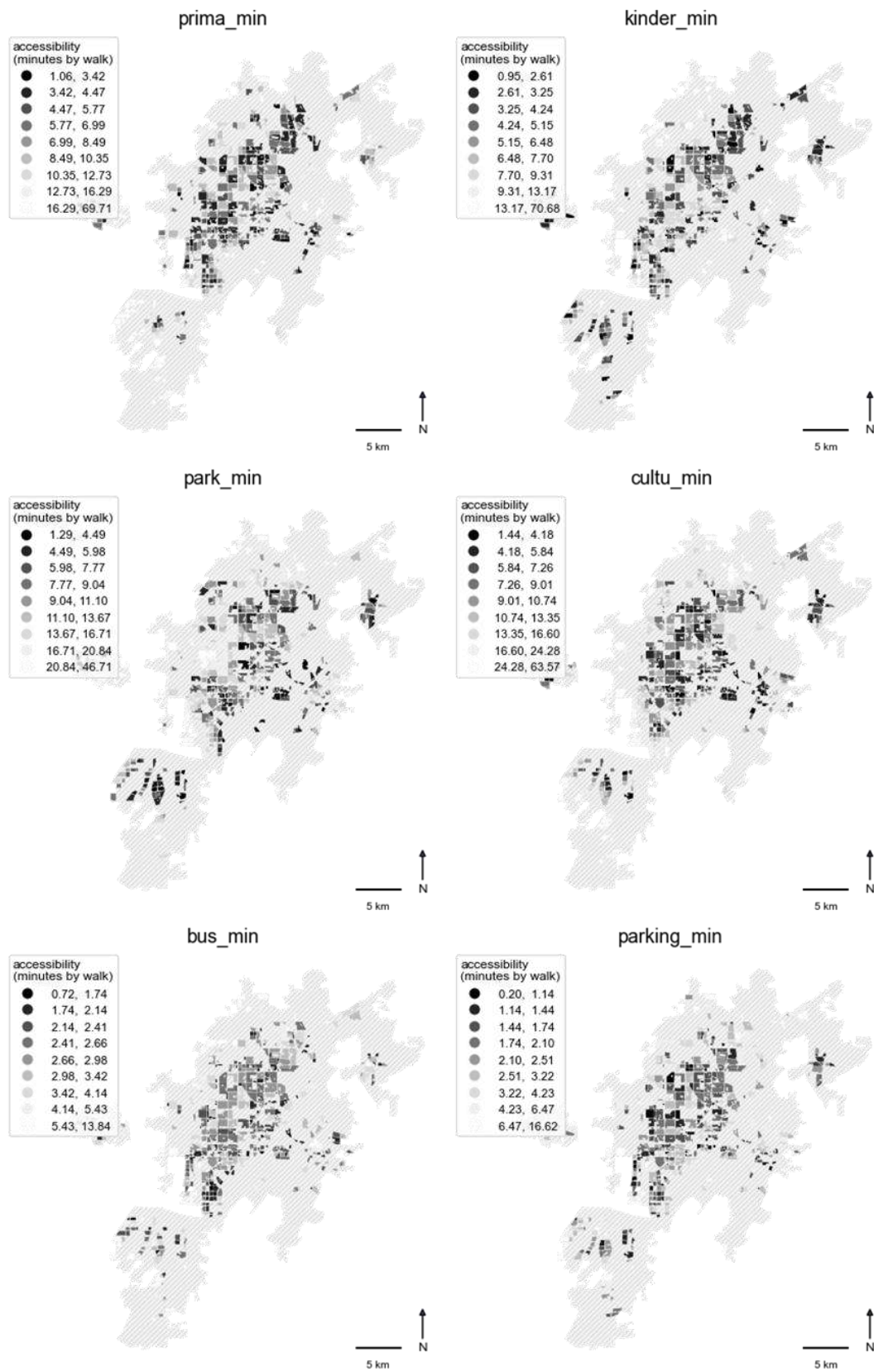


Figure 4.18 Accessibility of facilities

There are differences in the density of different types of facilities (Figure 4.19, Table 4.3). Firstly, from a map perspective, the density of various facilities within the downtown living circle is significantly higher than that in the suburbs, exhibiting a radial pattern of decreasing density from the core to the edge. Taking primary schools as an example, the density of primary schools within the walking living circle of downtown residential quarters ranges from 1.4 to 3.4 per square kilometer, while in peripheral areas, it is less than 0.9 per square kilometer, meaning there are no primary schools within a 15-minute walking radius. The higher density of facilities in the downtown area is primarily due to population concentration, high land use efficiency, and urban planning that tends to concentrate public services. Secondly, the box plot reflects differences in the density of living circles among different samples. For example, the median density of supermarkets ('superdenw') is 0.7, with 75% of the samples having a density not exceeding 1.52, but with a maximum value of 9.37 and a minimum value of 0, indicating that most living circles have a low density of supermarkets, and only some samples exhibit a concentrated supply characteristic. Overall, the Q1 – Q3 interval depicted by the box plot characterizes the typical density situation of most residents, while the minimum value indicates potential imbalances in facility layout. Finally, facility types can be divided into low-density and high-density categories. Low-density facilities include six types: educational facilities, cultural activity centers, parks and squares, and supermarkets. The median density of each type of facility is less than 1.57 per square kilometer. For example, the density of primary schools ranges from 0 to 3.4, with a median of 0.77. The remaining ten types of facilities are all high-density. Taking catering services as an example, they are widely distributed, with a density range of 0 – 250.8 per square kilometer and a median of 69.59. This means that more than half of the samples have a catering density greater than 69.59 per square kilometer within a 15-minute walking radius, which is approximately 90 times the density of primary schools.

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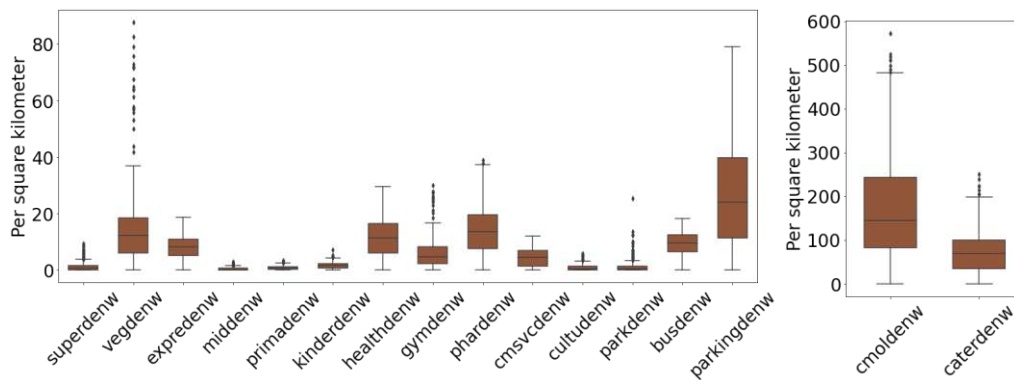
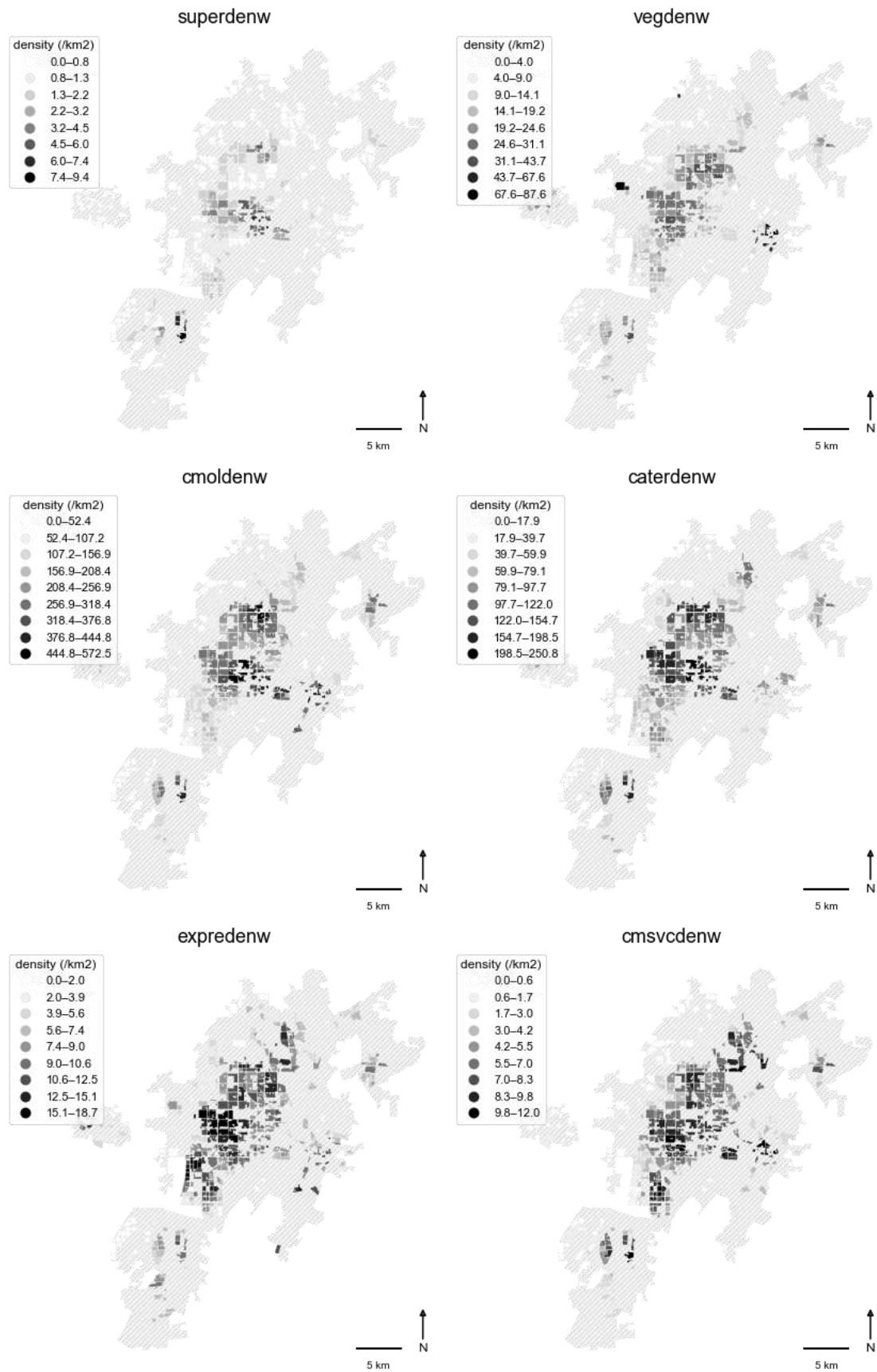


Figure 4.19 Box plot of single-type facility density

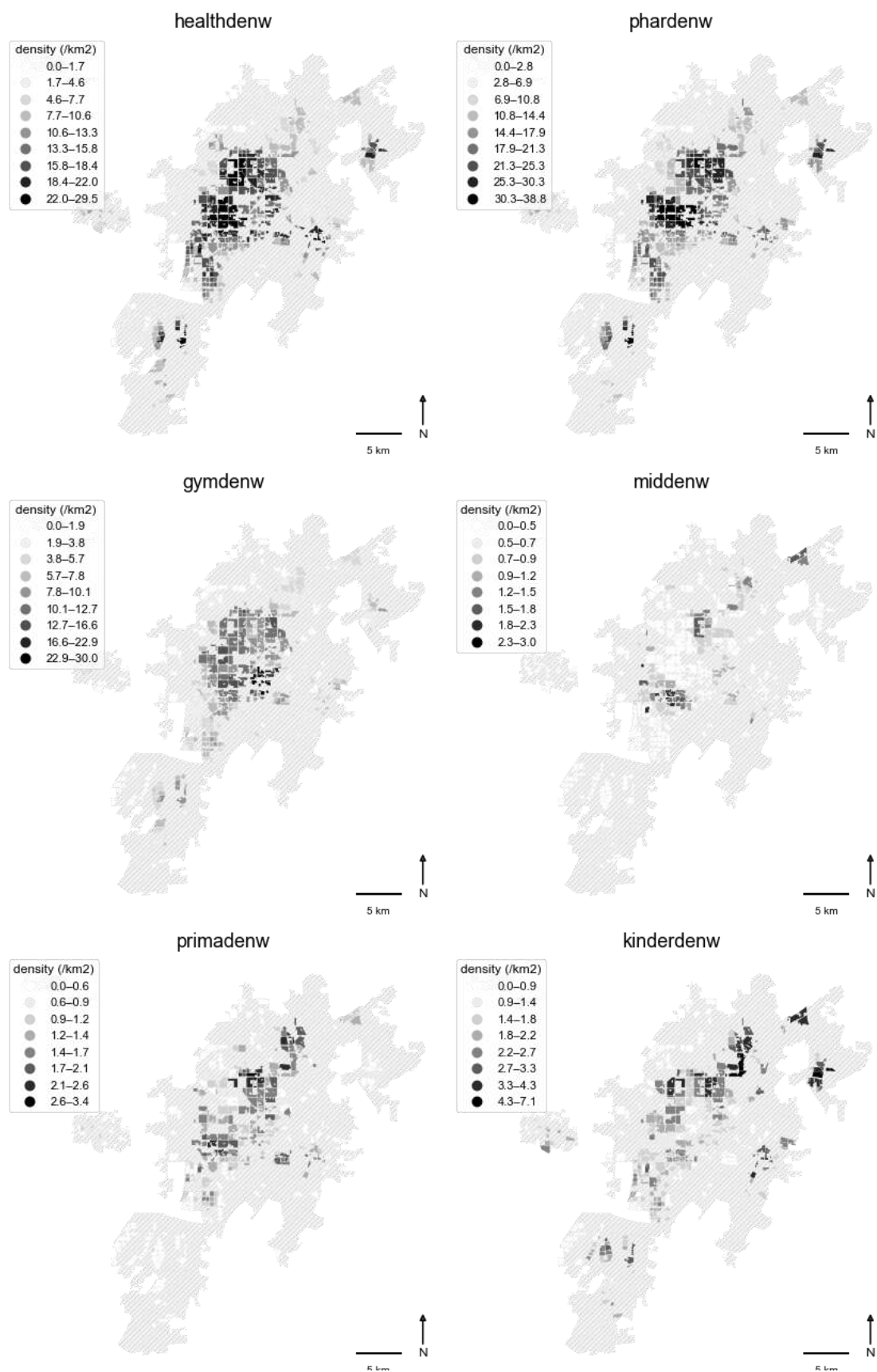
Table 4.4 Minimum, maximum, and percentile values for density of individual facility types

Per km ²	Indicator	q0	q25	q50	q75	q100
Shopping	superdenw	0	0	0.7	1.52	9.37
Shopping	vegdenw	0	6.02	12.34	18.58	87.65
Shopping	cmoldenw	0	83.52	146.19	243.69	572.54
Shopping	caterdenw	0	35.02	69.59	100.51	250.77
Shopping	expredenw	0	5.2	8.32	10.88	18.69
Learning	middenw	0	0	0	0.64	2.99
Learning	primadenw	0	0.38	0.77	1.23	3.4
Learning	kinderdenw	0	0.79	1.57	2.23	7.06
Caring	healthdenw	0	6.05	11.36	16.39	29.49
Caring	gymdenw	0	2.24	4.8	8.2	30.01
Caring	phardenw	0	7.69	13.61	19.67	38.79
Enjoying	cmsvcdenw	0	1.42	4.49	7.04	11.97
Enjoying	cultudenw	0	0	0.59	1.3	5.87
Enjoying	parkdenw	0	0	0.49	1.41	25.3
—	busdenw	0	6.46	9.65	12.58	18.25
—	parkingdenw	0	11.49	24.04	39.84	79.06

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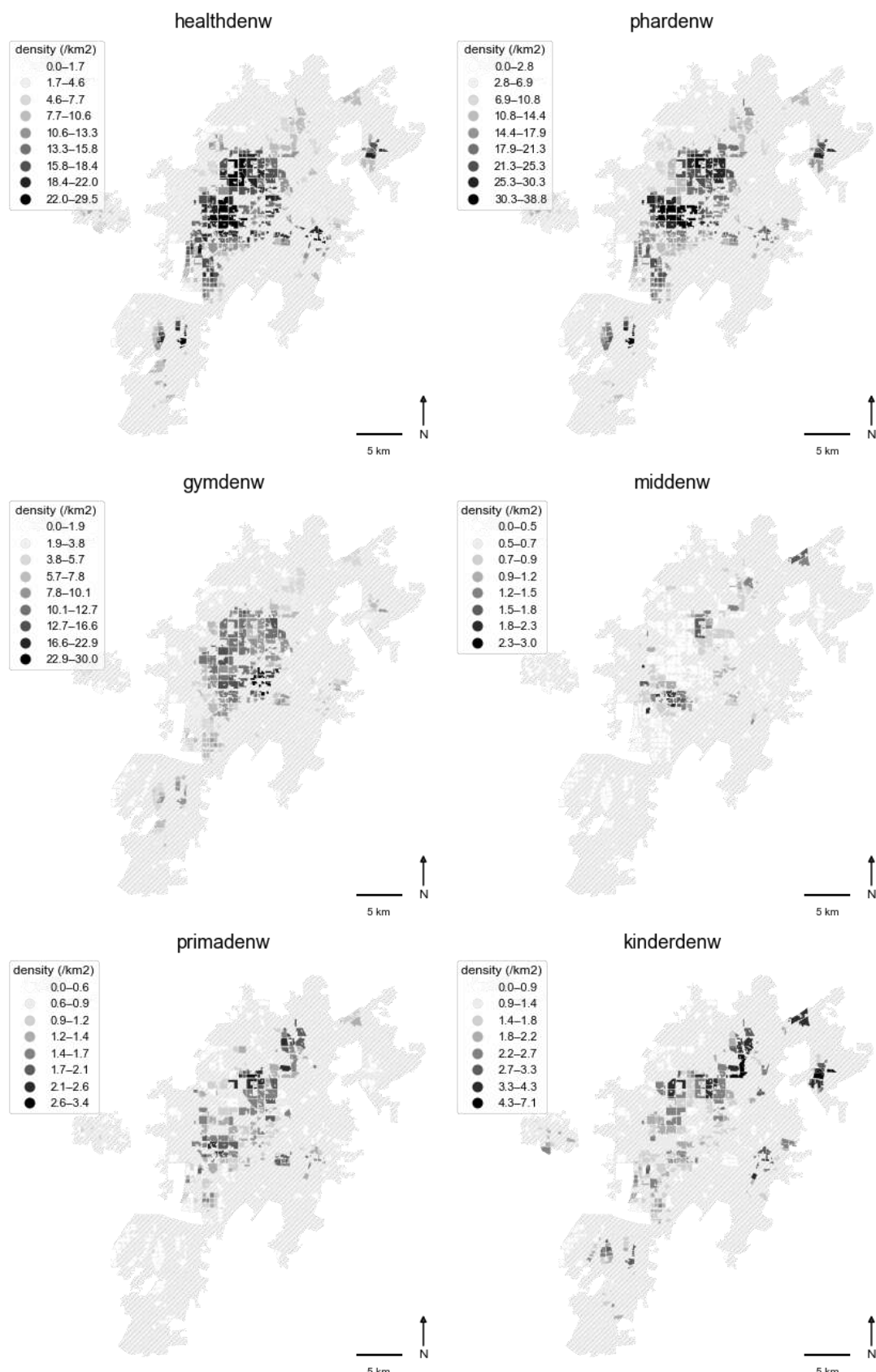


Figure 4.20 Density of facilities

4.1.4.3 Analysis of differences causes: low-density and low-accessibility facilities being independent and off-street

In summary, the results of facility density and facility accessibility are consistent, that is, low-density 6 types of facilities also exhibit low accessibility, while high-density 10 types of facilities also exhibit high accessibility. Therefore, 6 types of facilities will be represented by a special symbol in the following text, while the other 10 types will be visualized using a unified symbol. 16 types of facilities can be classified as scarce and non-scarce facilities, with low-density and low-accessibility corresponding to scarce facilities and high-density and high-accessibility corresponding to non-scarce facilities.

From the perspective of facility form, 6 types of scarce facilities are mostly independently occupied, typically with clear boundaries and dedicated land use, possessing a relatively large building area and land area, such as primary schools. On the other hand, 10 types of non-scarce facilities are mostly not independently occupied, often embedded within other building structures, with a smaller building area and land area, such as shops in ground-floor commercial areas.

From the perspective of facility location, the 6 types of scarce facilities are mostly arranged within non-street plots, often scattered sporadically in various urban spaces (Figure 4.21, Figure 4.22). This is related to the fact that these six types of facilities are mostly public welfare facilities that do not rely on passenger flow and can survive within non-street plots. It also reflects the planning concept of Tangshan residential quarters, which places facilities such as primary schools and cultural activity centers in the center of plots while arranging commercial facilities along the street, embodying the continuation and local transformation of neighborhood units. The 10 types of non-scarce facilities are mostly arranged along the street and on the edge of plots, often clustered along main roads, with a large number and high density, making most residential land in the city closer to them, thus overall exhibiting a higher level of density and accessibility. These independent variable results and layout analysis lay the foundation for the subsequent analysis of the impact mechanism of green travel and the proposal of facility renewal strategies.

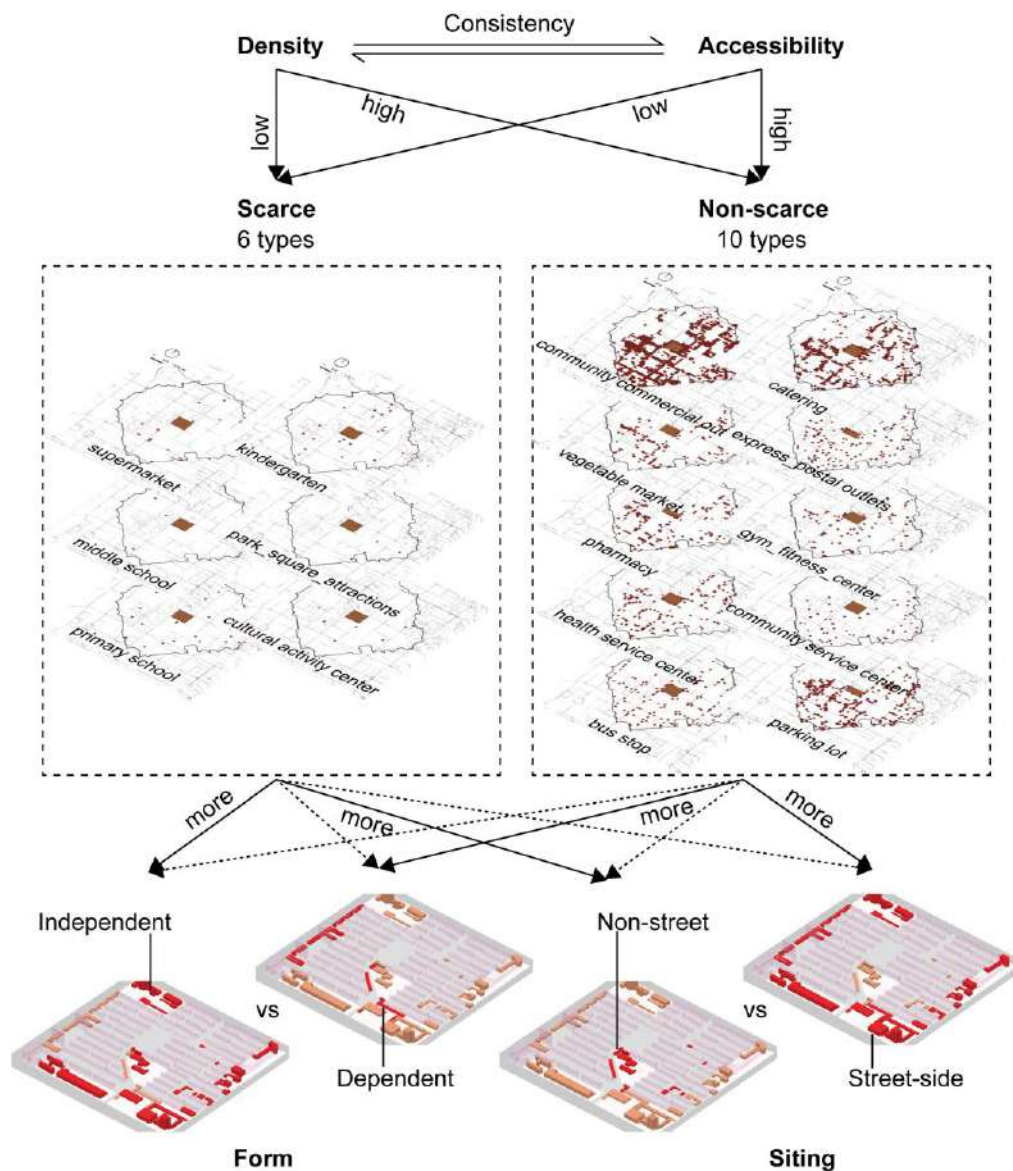


Figure 4.21 Explaining the characteristics of low density and low accessibility, as well as high density and high accessibility, of facilities based on their form and location

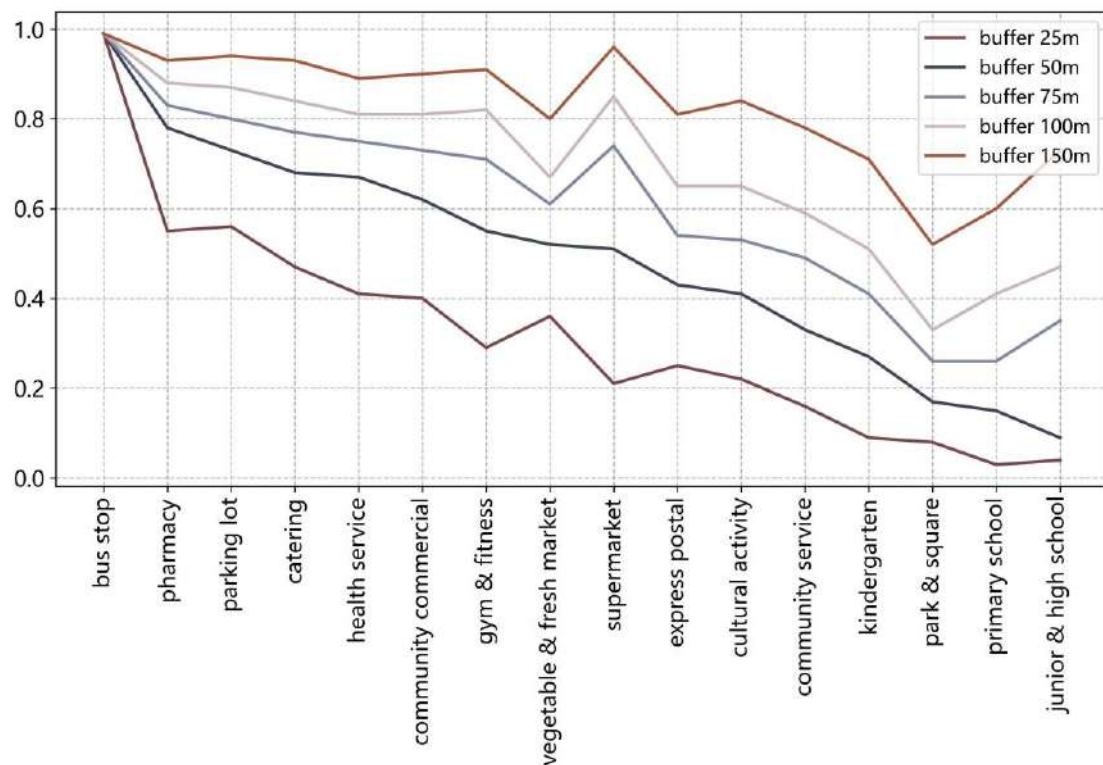


Figure 4.22 Percentage of 16 types of facilities along the street out of the total number

(with a buffer zone of x meters on both sides of the road centerline, and the number within the buffer zone is considered as the number along the street)

4.2 Methods

The study uses a random forest regression model combined with partial dependence analysis to characterize the sensitivity threshold of environmental variables in the surrounding streets of different facility types to green travel (walking and cycling) behavior.

4.2.1 XGBoost training and variable importance identification

The study uses the XGBoost model to analyze the relationship between facility layout and green travel proportion.

We constructed a green travel proportion prediction model using XGBoost and employed GridSearchCV for hyperparameter optimization. The parameter grid focuses on five key hyperparameters: “n_estimators,” “max_depth,” and “learning_rate.”

- **n_estimators:** Number of estimators (higher values increase accuracy but also

increase training time).

- **max_depth**: Maximum depth of the estimator (larger values increase model complexity).
- **learning_rate**: Affects model learning speed and performance; lower learning rates slow down convergence.
- **min_child_weight**: The minimum sum of sample weights required for a leaf node. Higher values make the model more conservative and reduce overfitting.
- **colsample_bytree**: The proportion of features used for each tree during construction (range from 0 to 1). For example, setting this to 0.7 means 70% of features are randomly selected for each tree.

These five parameters were set to: **n_estimators = 400**, **learning_rate = 0.01**, **max_depth = 10**, **min_child_weight = 6**, and **colsample_bytree = 0.7**. The training-to-testing data ratio was 8:2. When **n = 223** (ensuring that both walking and cycling data points in the 15-minute circles are ≥ 10), the model achieved an R^2 value of 64%, and the RMSE (Root Mean Squared Error) was 0.04, which indicates a good fit for social science studies, showing that the selected features can adequately explain the variation in green travel proportion.

After training the model, we analyzed feature importance using the built-in XGBoost feature importance metric, which measures the contribution of each feature based on its contribution to the tree splitting process. The importance values were extracted, sorted in descending order, and visually presented to demonstrate the relative contribution of each feature to predicting the green travel proportion.

4.2.2 SHAP Interpretation and green travel threshold extraction

One approach is to use Shapley values to plot partial dependence plots (PDPs), where the average SHAP value across all samples is used as the y-axis zero point to show each feature's effect on the predicted green travel proportion. A higher SHAP value indicates that the feature has a stronger positive impact on green travel. In this case, we used the LOWESS fitting method to capture the non-linear trend, evaluated the fit using R^2 , and identified key thresholds by analyzing intersections with the zero axis. This improves the visualization of feature importance and insights into the underlying mechanism.

Additionally, we computed the Shapley mean values for each living circle type to

identify the features that need improvement to promote green travel. For each feature, the same value corresponds to the same Shapley value, which allows for a comparison of Shapley means across different living circle types, helping us identify which features of each living circle favor or hinder green travel. Combining the mean of the features and the Shapley values reveals the “structural features” and “causal mechanisms” that can inform living circle optimization strategies.

4.2.3 Living circle clustering by weighted k-means and importance

The weighted K-means clustering method was used to classify the living circles. After determining the importance of each independent variable to the green travel proportion (based on the XGBoost model), we used the feature importance as weights to perform weighted K-means clustering on the 634 residential living circle samples. The reasons for choosing this method over other clustering methods are as follows (Table 4.5):

- 1 **Strengthens the clustering effect of green travel-related features:** Compared to unweighted clustering, this method focuses on the most explanatory variables of green travel, effectively reducing interference from redundant variables and making the clustering results more interpretable and goal-oriented.
- 2 **Preserves the original characteristics of living circle samples:** The clustering results differentiate living circles, ensuring that the internal samples of each cluster are similar in key variables, while external clusters show significant differences.
- 3 **Achieves stable identification of spatial patterns:** Given the high dimensionality of the features (46), using feature importance to weight the variables allows the preservation of high-dimensional information while ensuring interpretability and policy guidance.

4.2.4 Facility layout simplification by quadrant analysis

The quadrant method simplifies the facility layout features of a specific living circle into a quadrant for abstracting and refining its characteristics. Specifically, the method plots horizontal x- and vertical y-axes with the residential quarter centroid as the origin. Then, for the living circle, the radius of the 15-minute walking and cycling circles is calculated using the area formula $S = \pi r^2$, and arcs representing the two layers are drawn.

Table 4.5 Comparison table

Comparison Content	Weighted K-means (This Study)	Unweighted Clustering	SHAP-based Clustering
Considers Feature Importance	✓ Yes (Model-driven)	✗ No (Equal weight)	✓ Yes (Model output-based)
Preserves Feature Structure	✓ Yes (Original living circle features preserved)	✓ Yes (but no distinction with equal weight)	✗ No (Only preserves contribution vectors)
Goal-oriented	✓ Yes (Green travel-related variables focused)	✗ No	✓ Yes (Aligns with green travel prediction)
Transferability & Generalization	✓ High (Transferable)	⚠ Medium (Weak explanation)	✗ Poor (Explanation-focused, difficult to transfer)
High-dimensional Data Handling	✓ Strong (Weighting reduces noise variables)	✗ Weak (Sensitive to noise variables)	⚠ Average (Sensitive to sample disturbances)
Green Travel Mechanism Recognition	✓ Strong (Clustering results = Mechanism aggregation)	✗ Weak	✓ Strong (Mechanism alignment)
Operationality & Intervention Guidance	✓ High (Clear planning path)	⚠ Medium	✗ Weak (Difficult to implement)

Next, the horizontal and vertical distances from facilities to the residential quarter centroid are calculated to form the x- and y-axes coordinates. The quadrant method simplifies the complex facility layout system of the 15-minute cycling circle into a relatively simple spatial plane, visually presenting the directionality, concentration, and layer structure of the facility distribution, and verifying the spatial patterns of different living circles, thus providing a visual analysis foundation for layout optimization.

4.3 Regression results: importance and optimal ranges of variables to green travel

4.3.1 Importance: sensitivity differences in accessibility and density across facility types

4.3.1.1 Overall importance

We analyzed the importance of the 46 independent variables on the green travel proportion from overall, living circle, dimension, and facility category perspectives. The overall ranking and the top 3 features for each of the six dimensions are shown in the Figure 4.23.

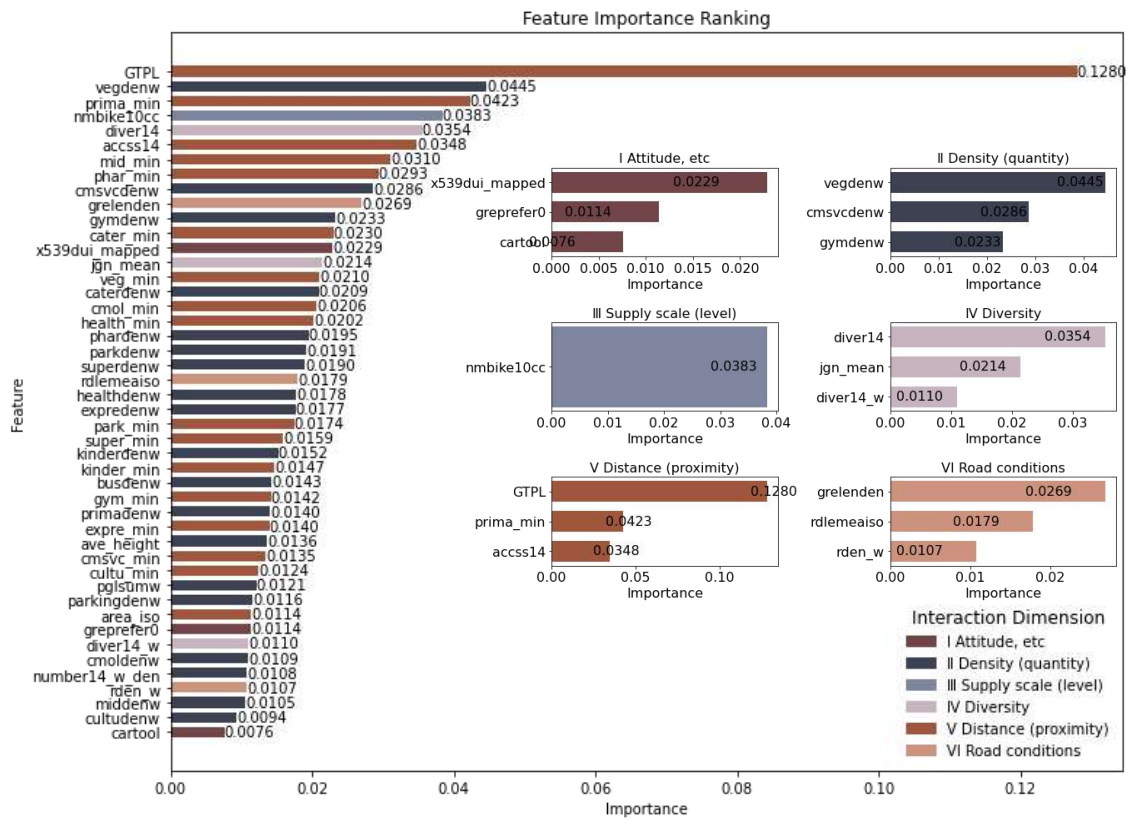


Figure 4.23 Overall importance

4.3.1.2 Importance of circles, dimensions, and facility categories

Comparing the three circles, the 15-minute walking circle has the greatest impact on the proportion of green travel (46.9%), followed by the cycling circle (45.4%), while the residential land has a relatively weaker impact (7.7%). It should be noted that the proximity measurement of facilities within the 15-minute cycling circle is based on the distance between the residential quarter and the nearest facility, which may be within the walking circle. Therefore, part of the importance of the cycling circle may be attributed to the walking circle.

Compared across six dimensions, the proportion of green travel is primarily influenced by accessibility (V) (46.4%) and density (II) (33.3%), followed by the coordination of factors such as diversity (IV), road conditions (VI), residents' attitudes (I), and facility scale (III).

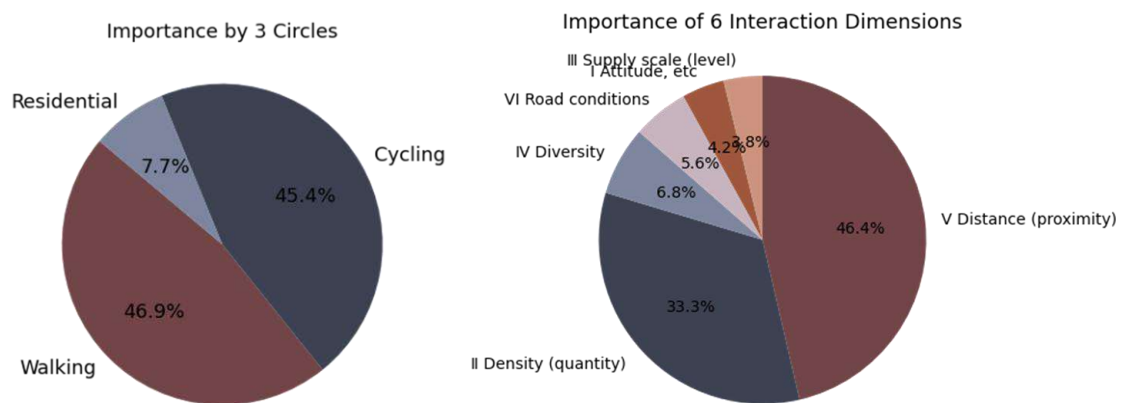


Figure 4.24 Comparison of importance, comparing from three circles (left) and six dimensions (right)

In terms of facility categories, shopping facilities contribute the most to green travel, with an importance coefficient of 0.207; followed by educational facilities, with an importance coefficient of 0.128, which is comparable to that of health facilities at 0.124; while leisure facilities (Enjoying) have the weakest impact, with an importance coefficient of only 0.100. Vegetable markets (veg, 0.066) and primary schools (prima, 0.056) remain the two most important types of facilities (Figure 4.24 up).

Further comparing from the two dimensions of accessibility and density (Figure 4.24 below), shopping facilities remain the most important (accessibility 0.094, density 0.113, both ranking first), with educational facilities having a higher accessibility (0.088, second, higher than the facility density of 0.040, fourth) and leisure and entertainment facilities having a higher density, while the accessibility and density of health facilities are equally important. The differences in the importance of accessibility and density among the four types of functions stem from the current layout of various facilities and user choice behavior. The following analysis will be conducted based on the current status of accessibility (min) and density (denw) (box plots and tables in Section 4.1.4).

Shopping facilities have high accessibility and density. The median distance between community commerce and vegetable markets is mostly within a 3-minute walking range, with a density significantly higher than other types (such as community commerce, with a median value of $146.2/\text{km}^2$). Coupled with high travel frequency and great choice flexibility, it has become the strongest driving factor for green travel.

The density of educational facilities (Learning) is less important than accessibility, because the density of such facilities is relatively low. The median density of junior high

schools and primary schools within a 15-minute walking circle in the sample is less than $1/\text{km}^2$, indicating that most residential quarters have only one school within their walking circle, and the density is far lower than that of other types of facilities, so the impact is inevitably weaker. Moreover, residents have a single choice for commuting to school, and they almost never increase their travel frequency or change their travel distance as the density of facilities increases. Therefore, green travel for educational facilities relies more on the accessibility of "nearest facilities" rather than a multi-point layout.

The importance of density and accessibility of health facilities (Caring) is on par. The median densities of stadiums and hospitals/clinics are 13.6 and 11.4 per square kilometer, respectively. Residents may not necessarily choose the nearest option for travel, such as for specific medical purposes, where density importance outweighs accessibility. The median accessibility of pharmacies is 2.61 minutes' walking distance, and given the small differences between them, residents tend to choose the nearest option, making accessibility even more important.

Leisure facilities (Enjoying) have the weakest impact on green travel, and density is the main driving factor. This type of facility is diverse in type, with multiple purposes and high flexibility of choice, making high-density layout significantly enhance residents' options and usage frequency. Typical facilities (such as cultural activity centers `cultu_min` and parks `park_min`) have a median accessibility of over 9 minutes' walking distance, and the density (`cultudenw`, `parkdenw`) is extremely low, about $0.5/\text{km}^2$, far lower than other facility categories. Coupled with the fact that leisure travel purposes are usually non-essential and the travel frequency is relatively low, this further weakens the actual role of such facilities in green travel.

In summary, the driving force of green travel for the four types of functional facilities is primarily influenced by the spatial distribution characteristics of the facilities, the frequency of usage demand, and the substitution elasticity of travel destinations. If a certain type of facility possesses a high-density layout, high-frequency usage demand, and strong substitution elasticity for travel destinations, its density has a more significant promoting effect on green travel.

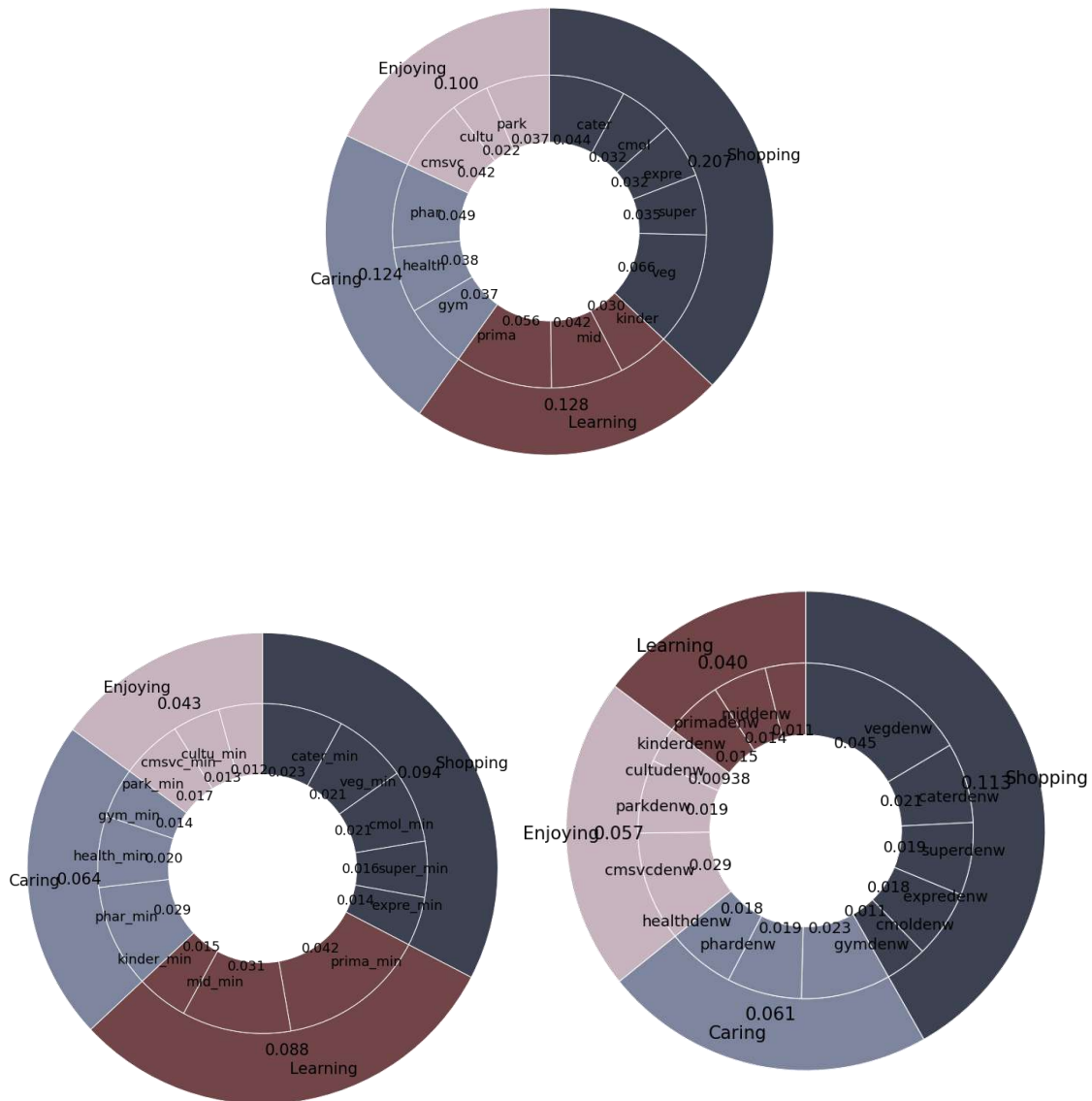


Figure 4.25 Comparison based on facility category (top) and comparison based on accessibility dimension and density dimension (bottom)

4.3.2 Optimal range: threshold effects of density and linear negative correlation of accessibility

4.3.2.1 Impact trends

Based on the trend of the impact of 46 variables on the dependent variable, it can be divided into 6 groups.

Group 1: Rising curve, including 6 independent variables. In this type, the independent variables have a positive correlation with the proportion of green travel.

When the independent variable is greater than 1-1, the local impact turns from negative to positive, entering the optimal range (1-1, $+\infty$). As the independent variable continues to increase, its positive impact on the proportion of green travel also continues to increase, reaching its maximum effect as it approaches positive infinity. Therefore, increasing this type of independent variable helps promote green travel, achieving the principle of "the higher, the better." For example, 1. The density of express delivery facilities, expressed as "expredenw," is positively correlated with the proportion of green travel. The higher the density of express delivery facilities, the greater the proportion of green travel. 2. When the density of express delivery facilities is greater than 11.57 per square kilometer, the local impact turns from negative to positive.

Group 2: Slowly Rising Curve, including 3 independent variables. This type shows that the independent variables are still positively correlated with the proportion of green travel, but the growth rate gradually slows down. When the independent variable exceeds 2-1, its local impact turns from negative to positive, entering the optimal range (2-1, $+\infty$). Within the interval (2-2, $+\infty$), the positive impact of the independent variable on green travel is most significant, with 2-2 considered as the balance point between land use and green travel. Therefore, in this type, the higher the independent variable, the more advantageous it is, but priority should be given to the optimal value close to 2-2. For example, the average spacing between main roads within a 1.15-minute cycling circle, rdlemeaiso, is positively correlated with the proportion of green travel, meaning that the larger the spacing, the higher the proportion of green travel. 2. When the spacing between main roads exceeds 326.51 per square kilometer, the local impact turns from negative to positive, but when the variable exceeds 360, the promotion effect remains unchanged.

Group 3: Curves with an initial increase followed by a decrease, encompassing 22 independent variables. Within this category, there exists an inverted V-shaped relationship between the independent variables and the proportion of green travel, indicating an initial positive correlation followed by a negative correlation. The optimal range is (3-1, 3-2), where the local impact of the independent variables is positive and reaches its maximum effect at 3-3. Beyond this value, the impact begins to weaken or even turn negative. Therefore, the independent variables should be controlled within the optimal range, with 3-3 being the optimal value. For example, 1. The correlation between bus stop density (busdenw) and the proportion of green travel exhibits an inverted V-shaped trend, with a peak at 10. 2. When bus stop density (busdenw) is within the range of 8.08 to 12.76, the

local impact on the proportion of green travel is positive.

Group 4: Descending curve, including 7 independent variables. These independent variables show a significant negative correlation trend with the proportion of green travel. They only have a certain positive effect within the interval (0, 4-1), and have a negative impact in other intervals. Therefore, the independent variables should be kept as low as possible, that is, "the smaller the better", in order to increase the likelihood of green travel. For example, 1. The accessibility of supermarkets, *super_min*, is negatively correlated with the proportion of green travel. The worse the accessibility of supermarkets (the longer the walking time), the lower the proportion of green travel. 2. When the accessibility of supermarkets is less than 6.08 minutes by walking, the local impact is positive.

Group 5: Decreasing Slowdown Curve, including 3 independent variables. This type exhibits an overall negative correlation, but the rate of decrease gradually slows down as the independent variables increase. The positive optimal range is concentrated in (0, 5-2), beyond which the positive effect quickly disappears. Therefore, controlling the independent variables within a lower range, especially not exceeding 5-2, is key to promoting green travel. For example, 1. The number of city centers within a 1.15-minute cycling circle, *nmbike10cc*, is negatively correlated with the proportion of green travel, meaning that the higher the number of city centers, the lower the proportion of green travel. 2. When the number of city centers is less than 3, the local impact is positive, and the level of positive impact is the same.

Group 6: The curve follows a pattern of decreasing first and then increasing, encompassing 5 independent variables. These independent variables exhibit a V-shaped impact on the proportion of green travel, demonstrating a dual effect of initially negative and subsequently positive influence. The optimal range is $(0, 6-1) \cup (6-2, +\infty)$, indicating positive promotion effects in both the low and high value segments. Consequently, the optimal value for the independent variable should be 0 or approach positive infinity to maximize green travel. For instance, 1. The density of cultural activity centers (stations) *cultudenw* has a V-shaped impact on the proportion of green travel, indicating bidirectional effects (positive and negative). 2. When the density of cultural activity centers (stations) is less than 1.04 or greater than 3.15 per square kilometer, it exerts a positive local impact on the proportion of green travel. Conversely, it has a negative local impact.

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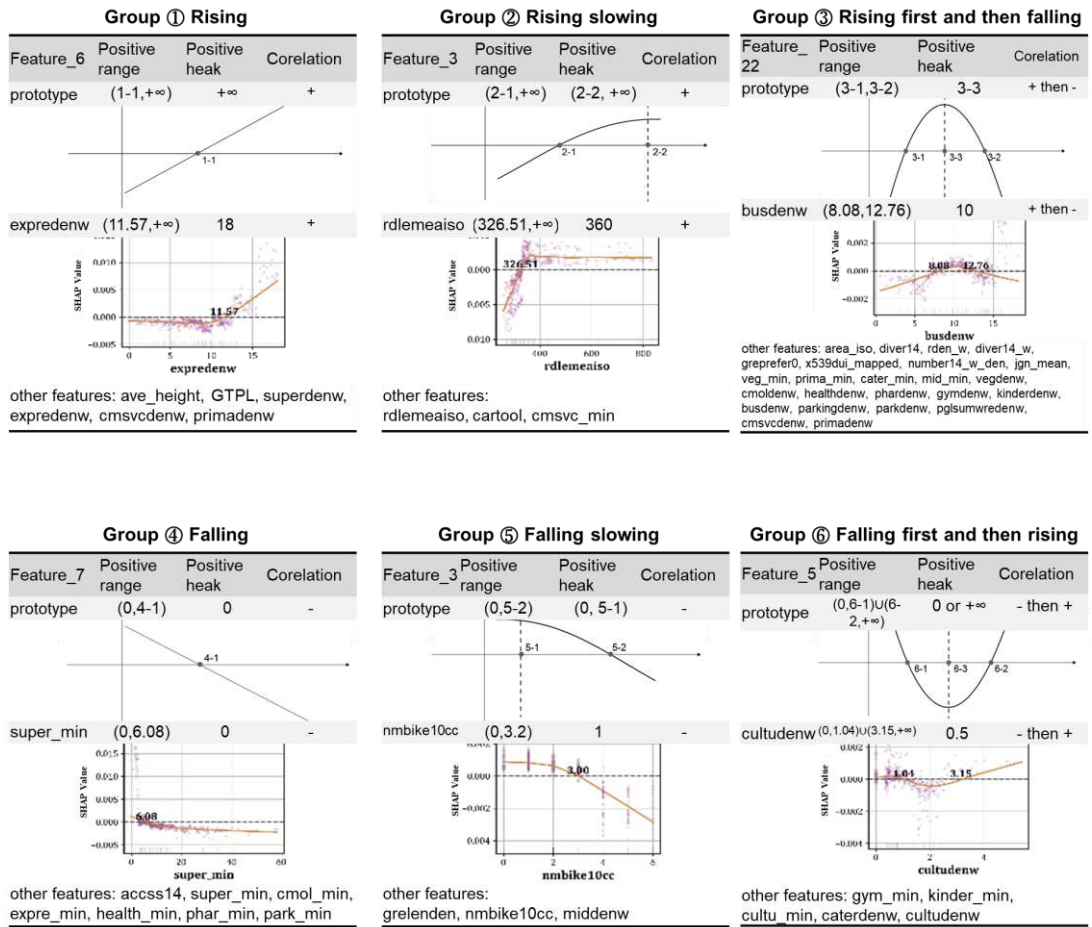


Figure 4.26 Trend curve of the impact of six types of independent variables on the dependent variable

4.3.2.2 Optimal ranges

The green travel optimal ranges for each independent variable are shown in the figures below and Table 4.6.

(1) Attitude

When X539_dui_mapped is less than 2.7, the local impact on the dependent variable is positive, indicating that affordable housing communities and commercial housing communities may be more conducive to green travel due to their high density, compactness, and mixed-use characteristics. In contrast, unit-based communities and village-to-residential communities often face situations of low density or single-functional areas, which may be farther away from service facilities, leading residents to rely more on car travel, and having poorer accessibility for walking and cycling.

Greprefer0 has a positive local impact on the proportion of green travel within the range of 0.57 to 1.75.

When the impact of Cartool is greater than 0.33, it is considered positive, indicating that a high car ownership rate does not necessarily correspond to non-green travel. This is because areas with high car ownership rates are usually accompanied by a higher level of urbanization. Factors such as the completeness of transportation facilities and the reasonable layout of living areas make residents more inclined to choose green travel modes for short-distance trips, rather than relying on cars for long-distance or emergency travel.

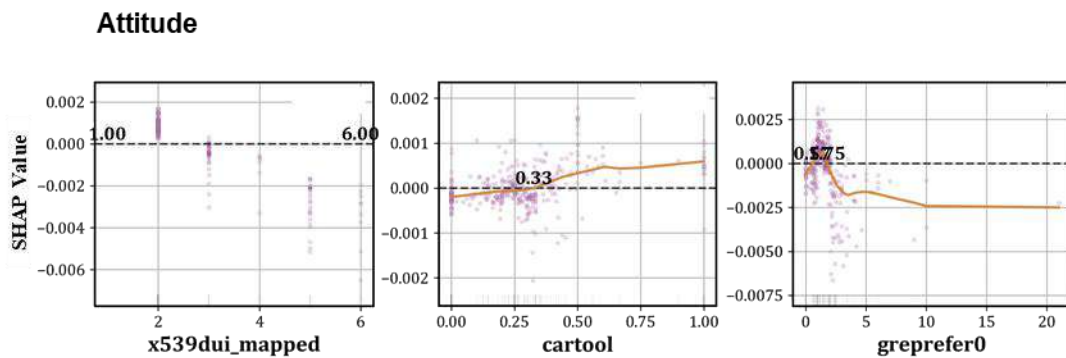


Figure 4.27 Green travel optimal range of each independent variable of Attitude dimension

(The value on the Y-axis represents the contribution of the independent variable to the dependent variable, green travel proportion. A y value greater than 0 indicates a positive impact on green travel, and the set of x values corresponding to these samples can be considered the optimal range. A y value less than 0 indicates a negative impact, and a y value equal to 0 indicates no impact. The same applies hereinafter)

(2) Density

Number14_w_den is greater than 400 and less than 615.67 per square kilometer, promoting green travel. Because it can ensure a moderate facility density, allowing residents to access sufficient service facilities within a reasonable walking distance, while avoiding overcrowding, traffic congestion, environmental deterioration, and other issues. Such a facility distribution can create a more comfortable and livable walking environment, encouraging walking and cycling.

The correlation between single-type facilities such as vegdenw, cmoldenw, healthdenw, phardenw, gymdenw, kinderdenw, parkdenw, busdenw, and parkingdenw and the proportion of green travel also exhibits a nonlinear inverted V trend. This indicates that beyond a certain threshold range, increasing the density of these facilities may be

ineffective or even diminish, possibly due to "facility fatigue" caused by over-choice and spatial crowding, leading to overexploitation of resources and resulting in lower utilization rates and decreased actual utility of individual facilities. The optimal ranges for vegdenw, kinderdenw, busdenw, parkingdenw, and phardenw are 7.73-14.88, 1.31-3.71, 8.08-12.76, 25.31-57.84, and 14.15-35.36, respectively, which have a positive impact on green travel. The optimal values for these facilities are at different levels, with parkdenw having the smallest optimal value (0.18), gymdenw having an optimal value of 4, healthdenw having an optimal value of 10, and cmoldenw having the largest optimal value (100).

Similarly, the curves for caterdenw, cultudenw, and pglsumw also exhibit nonlinear trends. When caterdenw is less than 81.03 or greater than 215 per square kilometer, cultudenw is less than 1.04 or greater than 3.15 per square kilometer, and Pglsumw is greater than 250,000 and less than 358,022.40 square meters, green travel is promoted.

There are four types of facilities that can break "facility fatigue" and positively correlate with the proportion of green travel. When superdenw, expredenw, cmsvdenw, and primadenw are greater than 3.43, 11.57, 6.41, and 1.75 per square kilometer, respectively, they can consistently promote green travel. On the one hand, these facilities are daily necessities and are used frequently, making walking and cycling to these facilities a daily choice and habit for residents. On the other hand, these facilities provide social spaces for residents, reducing people's dependence on private cars for leisure travel, group travel, and other situations.

On the contrary, Middenw promotes green travel when it is less than 0.41 per square kilometer, possibly due to the larger scale of junior high schools or their infrequent use (some residential quarters have fewer junior high school students), and their low density, which is conducive to saving land for other small-scale, commonly used facility types.

When Ave_height exceeds 19.08m, it promotes green travel. Ideally, it should be greater than 50m for optimal performance. High-rise residential buildings often correspond to high residential population density, which in turn leads to high-density facilities and high convenience.

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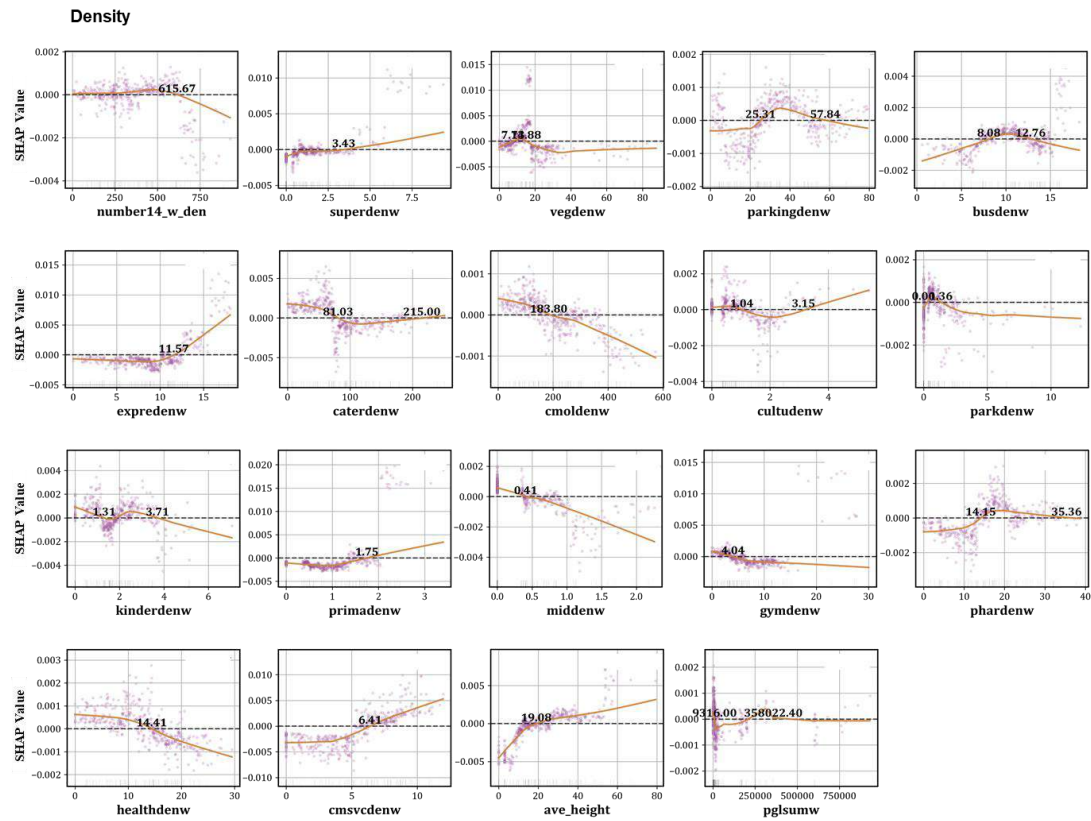


Figure 4.28 Green travel optimal range of each independent variable of Density dimension

(3) Scale

The number of city centers within a 15-minute living circle, Nmbike10cc, should be less than or equal to 3.2, which has a positive impact on the proportion of green travel. The reason may be that the greater the number of city center nodes, the more travel destinations residents can choose from, the weaker their dependence on local facilities becomes, the increased demand for long-distance travel, and the longer travel distances, leading to less green travel.

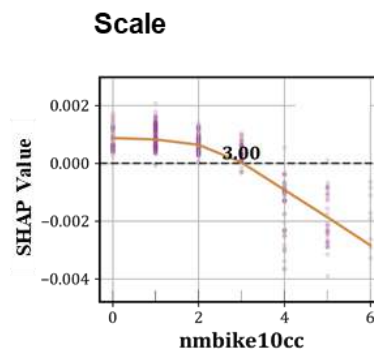


Figure 4.29 Green travel optimal range of independent variable of Scale dimension

(4) Diversity

The optimal value for Diver14 is approximately 1.4.

When Diver14_w is greater than 1.40 and less than 1.60, it has a positive impact on the proportion of green travel. A medium to high level of diversity can enhance the environmental appeal, thereby promoting green travel.

Between 2000 and 2011, Jgn_mean favored green travel, possibly due to the promotion of policies, changes in urban planning, construction of infrastructure, and the enhancement of society's awareness of green travel during this period. Early residential quarters (especially those built before the 1970s) were often single-functional areas located far from service facilities, and residents' travel relied more on cars. Newer residential quarters (especially those built after 2012) may be new districts where services have not yet formed a scale.

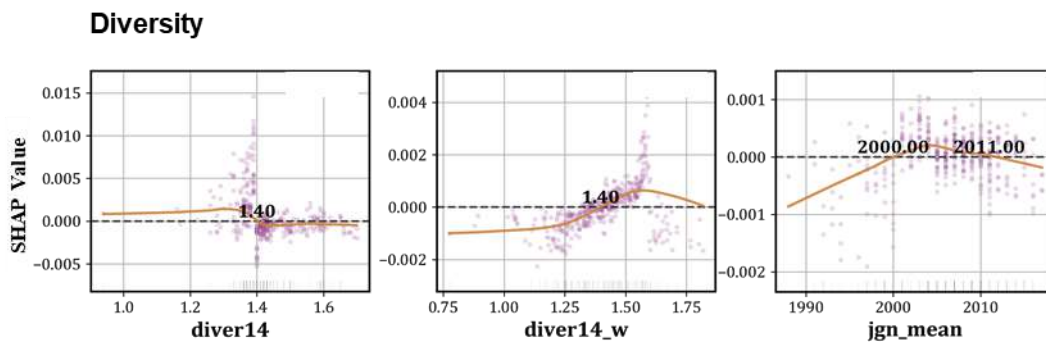


Figure 4.30 Green travel optimal range of each independent variable of Diversity dimension

(5) Accessibility

Consistent with expectations, the closer the majority of facilities are, the more beneficial it is for green travel.

The values of Accss14, super_min, cmol_min, expre_min, health_min, phar_min, and park_min are less than 5.35, 6.08, 1.08, 1.98, 1.89, 2.2, and 8.89, respectively, which have significant positive local impacts on the proportion of green travel. In particular, super_min with a value of 6.08 serves as a clear watershed, indicating that reaching supermarkets by foot is of great importance to residents' lives during this time period.

The optimal ranges and optimal values for other types of facilities are slightly shifted to the right. The optimal values for veg_min, prima_min, cater_min, mid_min, gym_min, kinder_min, cultu_min, and cmsvc_min are 2.5, 5, 5, 14, 2.5, 3, 5, and 20, respectively.

This indicates that these facilities can be located slightly farther from residential quarters to promote green travel. It reflects that medium-distance grocery markets, dining, and educational facilities may be more frequently used by or suitable for residential quarters.

When GTPL is greater than 0.49, the local impact on the dependent variable shifts from negative to positive, indicating that the level of green travel within a 15-minute walking circle will be improved.

Area_iso has a positive local impact on green travel within the range of 16,316,337.66 to 21,000,000 and 23,000,000 to 30,626,708.62. An excessively small living area often corresponds to a lower road density, affecting travel convenience.

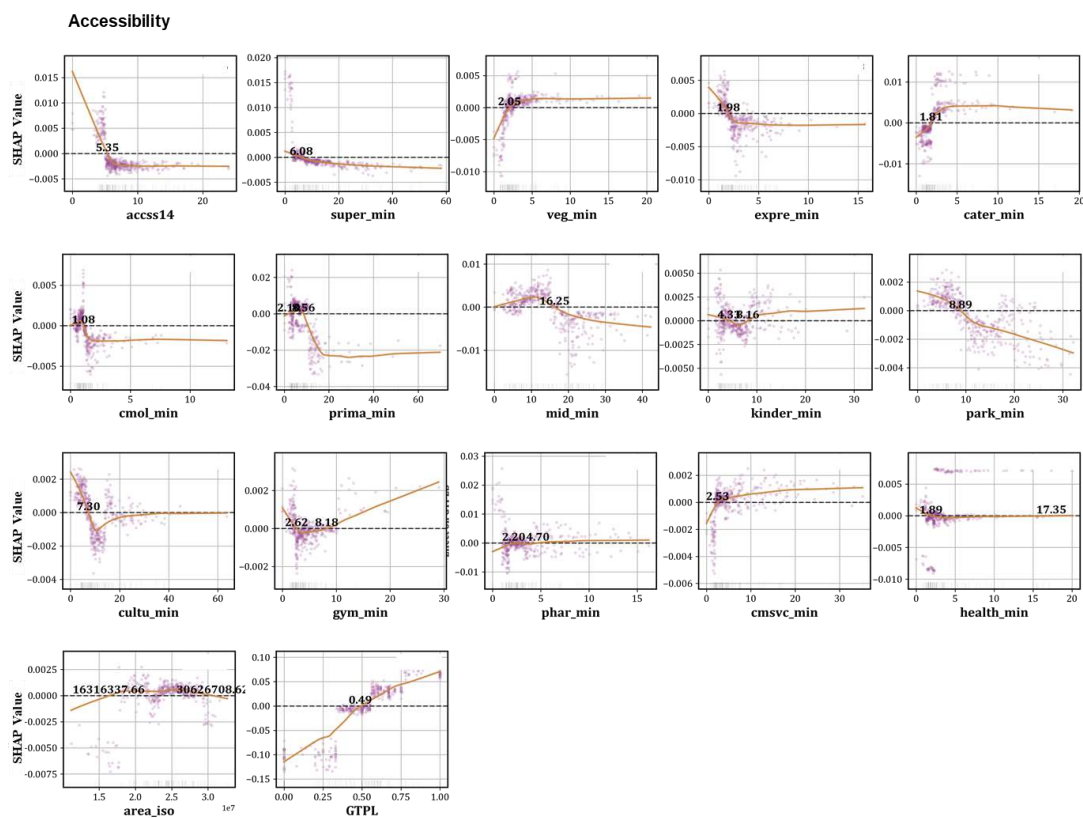


Figure 4.31 Green travel optimal range of each independent variable of Accessibility dimension

(6) Road condition

Grelenden is less than 3112.59, which has a positive local impact on green travel.

The main road spacing Rdlemeaiso is greater than 326.51, which has a positive impact. The larger the main road spacing, the more effective it is in improving the travel environment for cyclists, reducing traffic interference and congestion, and enhancing the safety, comfort, and connectivity of cycling. This design not only provides cyclists with

more independent cycling space, avoiding conflicts with motor vehicles, but also makes green travel more attractive, thereby promoting the proportion of cycling and walking. Compared with existing research, which generally believes that small blocks are conducive to walking, this study includes cycling, so the conclusion is slightly different from previous studies. On the other hand, influenced by the concept of "dense network of small blocks", the main road spacing in Tangshan New Area is smaller than that in the city center, and the proportion of green travel is lower, which can also explain this result.

Rden_w promotes green travel within the range of 2.20 to 5.25 kilometers per square kilometer. This may be due to the fact that such road density can ensure a balance between transportation land, connectivity, and facility density within a 15-minute walking radius, thereby guaranteeing travel convenience and green travel. If the road density is too low, facilities may be too dispersed, leading to residents needing longer time to reach these facilities, thus reducing the possibility of walking. If the road density is too high, it may lead to heavy traffic, excessive traffic flow, and noise, which in turn will affect the comfort and safety of walking. The optimal Rden_w is 3.75 kilometers per square kilometer, which has the strongest local positive effect on the proportion of green travel.

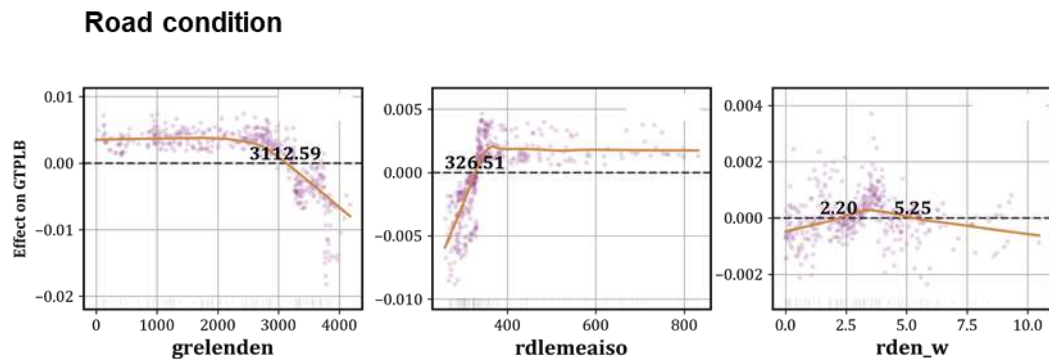


Figure 4.32 Green travel optimal range of each independent variable of Road condition dimension

Table 4.6 Optimal ranges of each independent variable

Six Interaction Dimensions	Feature	Importance	Rank	Positive range	Positive peak	Correlation
Attitude	x539dui_map	0.023	13	(0,2.7)	2	+ then -
	greprefer0	0.011	39	(0.57,1.75)	1	+ then -
	cartool	0.008	46	(0.33,+∞)	0.6	+
Density	vegdenw	0.045	2	(7.73,14.88)	14	+ then -
	cmsvcdenw	0.029	9	(6.41,+∞)	12	+

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	gymdenw	0.023	11	(0,4.04)	4	+ then -
	caterdenw	0.021	16	(0,81.03) $\cup$ (215, $+\infty$)	65	- then +
	phardenw	0.019	19	(14.15,35.36)	20	+ then -
	parkdenw	0.019	20	(0,0.36)	0.18	+ then -
	superdenw	0.019	21	(3.43, $+\infty$)	9	+
	healthdenw	0.018	23	(0,14.41)	10	+ then -
	expredenw	0.018	24	(11.57, $+\infty$)	18	+
	kinderdenw	0.015	27	(1.31,3.71)	3	+ then -
	busdenw	0.014	29	(8.08,12.76)	10	+ then -
	primadenw	0.014	31	(1.75, $+\infty$)	3.4	+
	ave_height	0.014	33	(19.08, $+\infty$)	80	+
	pglsumw	0.012	36	(250000,358022.4 0)	2800 00	+ then -
	parkingdenw	0.012	37	(25.31,57.84)	30	+ then -
	cmoldenw	0.011	41	(0,183.80)	100	+ then -
	number14_w_ den	0.011	42	(400,615.67)	600	+ then -
	middenw	0.011	44	(0,0.41)	0.41	-
	cultudenw	0.009	45	(0,1.04) $\cup$ (3.15, $+\infty$)	0.5	- then +
Scale	nmbike10cc	0.038	4	(0,3.2)	1	-
Accessibility	GTPL	0.128	1	(0.49, $+\infty$)	1	+
	prima_min	0.042	3	(2.1,8.56)	5	+ then -
	acess14	0.035	6	(0,5.35)	0	-
	mid_min	0.031	7	(8,16.25)	14	+ then -
	phar_min	0.029	8	(0,2.2)	0	-
	cater_min	0.023	12	(1.81, $+\infty$)	5	+ then -
	veg_min	0.021	15	(2.05, $+\infty$)	2.5	+ then -
	cmol_min	0.021	17	(0,1.08)	0	-
	health_min	0.020	18	(0,1.89)	0	-
	park_min	0.017	25	(0,8.89)	0	-
	super_min	0.016	26	(0,6.08)	0	-
	kinder_min	0.015	28	(0,4.33) $\cup$ (8.16, $+\infty$)	3	- then +
	gym_min	0.014	30	(0,2.62) $\cup$ (8.18, $+\infty$)	2.5	- then +
	expre_min	0.014	32	(0,1.98)	0	-
	cmsvc_min	0.013	34	(2.53, $+\infty$)	20	+
	cultu_min	0.012	35	(0,7.3) $\cup$ (15, $+\infty$)	5	- then +
	area_iso	0.011	38	(16316337.66, 21000000) $\cup$ (23000000, 30626708.62)	2700 0000	+ then -
Diversity	diver14	0.035	5	(0,1.4)	1.4	+ then -
	jgn_mean	0.021	14	(2000,2011)	2004	+ then -
	diver14_w	0.011	40	(1.4,1.65)	1.6	+ then -

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Road condition	grelanden	0.027	10	(0,3112.59)	2500	-
	rdlemeaiso	0.018	22	(326.51,+∞)	360	+
	rden_w	0.011	43	(2.2,5.25)	3.75	+ then -

4.4 Clustering results: six living circle clusters and characteristics

Based on the weighted K-Means method and the Elbow Method for evaluating clustering results, we determined the optimal number of clusters to be **K=6**. The **Within-Cluster Sum of Squares (WCSS)** curve displayed a clear "elbow" at K=6, indicating that increasing the number of clusters further provided diminishing returns in terms of reducing WCSS. Therefore, K=6 was chosen as the optimal number of clusters for this study's living circle classification (APPENDIX Figure E.2).

4.4.1 Balanced high and low clusters as green travel characteristics

- **Cluster 0:** The green travel proportion is the lowest at **0.415263**, with only **57** living circles in this category, indicating a significant opportunity for improvement in green travel.
- **Cluster 1:** The green travel proportion is **0.489722**, close to the overall average, indicating a moderately low level of green travel. It is the most frequent category, comprising **180** living circles. This type has a wide distribution but requires further optimization in walkability and cycling convenience.
- **Cluster 2:** The green travel proportion is the highest at **0.589857**, indicating strong green travel characteristics. It includes **70** living circles, which are moderately distributed and represent a well-organized facility layout, street environment, and resident preference for green travel.

Table 4.7 Number of various living circle types and proportions of green travel as the dependent variable

cluster	cluster_count	Mean_Green_travel_prop_life
0	57	0.415263
1	180	0.489722
2	70	0.589857
3	163	0.503313
4	90	0.540778
5	74	0.434054

- **Cluster 3:** The green travel proportion is **0.503313**, slightly above the average. With **163** living circles, this category has good potential for green travel improvement through targeted adjustments.
- **Cluster 4:** The green travel proportion is **0.540778**, ranking second highest. This category includes **90** living circles, showing favorable conditions for green travel that should be reinforced in future urban planning.
- **Cluster 5:** The green travel proportion is **0.434054**, slightly higher than Cluster 0 but still low. This group comprises **74** living circles, indicating that their green travel potential has not been fully realized and requires further investigation for improvement.

4.4.2 Central compact vs. peripheral fragmented clusters as spatial characteristics

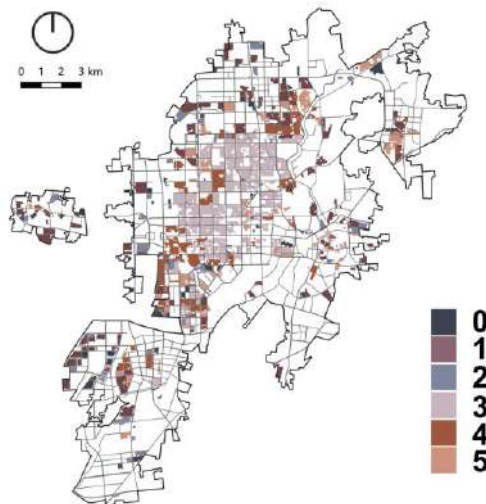


Figure 4.33 Spatial distribution of six types of living circles

The spatial distribution of living circles is shown in the Figure 4.33.

- **Cluster 0:** Mainly distributed in urban-rural fringe areas and suburban towns, with low green travel proportions due to being far from city centers or town centers.
- **Cluster 1:** Located at the urban edge or fragmented zones away from the city center, these living circles are surrounded by large vacant lots, undeveloped or idle plots.
- **Cluster 2:** Residential quarters along major roads extending from the urban edge, especially in TOD (Transit-Oriented Development) zones, are characterized by

compact and well-connected facilities. These areas offer easy access to various services, supporting green travel.

- **Cluster 3:** Located in the city center, these living circles occupy the most central parts of the city, with strong connectivity and comprehensive service provisions.
- **Cluster 4:** Located near the city center but further than Cluster 3, this category includes living circles built between **1986 and 1994**, featuring balanced and diverse facilities that support green travel.
- **Cluster 5:** Located in peripheral areas, these living circles are near non-residential land uses (e.g., industrial, office, or large city parks).

Subsequently, the characteristics of six types of living circles are analyzed from two dimensions: the layout features of living circle facilities and the layout features of green travel facilities, in order to create a portrait of the living circles. The first dimension, facility layout features, each type of living circle possesses prominent features (corresponding to zones 1 and 3 in Figure 4.34) or mediocre features (corresponding to zone 2), with this paper focusing on the prominent features. The second dimension, green travel facility layout features, each type of living circle exhibits a certain feature that either promotes green travel (corresponding to zone B in Figure B) or inhibits green travel (corresponding to zone A). This paper focuses on promoting or inhibiting features according to the type of living circle.

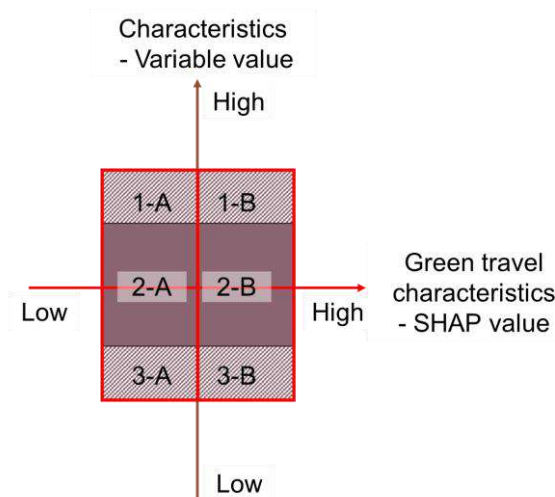


Figure 4.34 Analysis framework

4.4.3 Density and accessibility as cluster facility layout differences

For each independent variable within each type of living circle, we calculate the

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sample mean to extract the characteristics of facility layout in the living circle (Table 4.8). The core prominent features of various living circles are evaluated through high values (corresponding to Zone 1) or low values (corresponding to Zone 3 in Figure 4.34).

Table 4.8 Mean values of variables for six living circle clusters and overall city average

	Feature	0	1	2	3	4	5	mean
0	accss14	8.41	10.93	9.8	5.27	6.22	7.58	8.06
1	ave_height	18.84	17.84	22.87	21.23	23.11	17.99	20.12
2	area_iso	23349435 .97	206287 48.59	220828 12.93	2617001 7.6	2425340 7.48	2354119 7.52	2329944 1.53
3	grelenden	2218.02	1375.56	1891.26	3095.85	2698.34	2184.18	2229.11
4	diver14	1.44	1.4	1.44	1.42	1.47	1.44	1.43
5	rden_w	2.78	1.86	2.8	4.03	3.13	2.47	2.86
6	rdlemeaiso	371.06	431.73	419.81	327.25	335.48	370.5	377.53
7	GTPL	0.01	0.53	0.98	0.5	0.68	0.31	0.52
8	diver14_w	1.41	1.34	1.4	1.4	1.45	1.42	1.39
9	cartool	0.26	0.32	0.21	0.27	0.29	0.31	0.28
10	greprefer0	1.9	1.77	1.82	1.74	1.48	1.69	1.71
11	x539dui_map ped	2.91	2.81	2.54	2.87	2.41	2.81	2.75
12	nmbike10cc	1.84	0.73	1.19	3.11	2.18	1.54	1.79
13	number14_w _den	287.6	164.99	240.61	477.45	339.93	323.51	308.97
14	jgn_mean	2006.96	2007.68	2007.63	2004.81	2006.96	2006.72	2006.67
15	super_min	14.99	19.06	15.3	7.26	9.98	12.62	13.2
16	veg_min	4.15	6.03	4.34	2.49	2.76	3.29	3.98
17	prima_min	10.44	13.21	12.85	5.95	6.95	9.51	9.73
18	cmol_min	1.57	2.36	1.76	1.02	1.2	1.49	1.61
19	cater_min	2.59	3.92	2.89	1.56	1.75	2.45	2.6
20	expre_min	3.49	4.2	3.41	2.31	2.47	3.2	3.2
21	cmsvc_min	7.44	11.43	11.24	3.14	4.75	6.07	7.34
22	health_min	4.95	5.82	5.01	2.39	2.91	3.7	4.11
23	phar_min	3.75	5.36	3.86	2.32	3.12	3.53	3.74
24	gym_min	5.68	6.92	5.88	3.25	3.82	4.48	5.03

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Table 5.6 Mean values of variables for six living circle clusters and overall city average
(Continued)

	Feature	0	1	2	3	4	5	mean
25	mid_min	13.82	21.01	16.79	10.73	12.03	15.04	15.28
26	kinder_min	7.19	9.72	7.99	5.7	5.19	6.21	7.21
27	park_min	12.39	12.57	13.48	9.48	11.25	11.17	11.51
28	cultu_min	13.3	15.24	15.53	7.21	10.74	11.55	11.96
29	superdenw	0.87	0.39	0.84	2.08	1.3	1.13	1.14
30	vegdenw	12.36	8.25	13.21	20.04	16.19	16.52	14.36
31	cmoldenw	157.82	92.48	129.63	266.85	180.76	180.16	170.47
32	caterdenw	70.97	36.88	59.24	116.58	85.59	75.86	74.66
33	expredenw	7.88	5.52	6.66	10.86	9.55	7.99	8.12
34	cmsvcdenw	4.21	2.03	3.02	7.04	5.18	4.82	4.41
35	healthdenw	10.63	5.97	8.69	17.24	13.91	11.49	11.4
36	phardenw	12.97	7.4	11.07	21.16	15.83	14.18	13.88
37	gymdenw	5.25	2.52	4.55	9.59	6.56	6.2	5.83
38	middenw	0.48	0.14	0.27	0.57	0.51	0.26	0.36
39	primadenw	0.83	0.4	0.61	1.23	1	0.77	0.81
40	kinderdenw	1.42	1.18	1.47	1.79	1.81	2.1	1.6
41	parkdenw	0.96	1.3	0.74	1.21	0.96	1.15	1.11
42	cultudenw	0.94	0.52	0.62	1.21	0.77	0.88	0.83
43	busdenw	9.81	6.38	7.41	12.66	10.71	9.37	9.41
44	parkingdenw	25.32	13.21	19.13	43.9	31.47	26.29	27.04
45	pglsumw	77590.32	71813	73512.9 8	53296.5 9	50391.4 7	73888.5	64980.4 3
46	Green_travel_ prop_life	0.42	0.49	0.59	0.5	0.54	0.43	0.5

Within-cluster analysis, with the exception of a few indicators such as parkdenw and pglsumw, which exhibited divergent performance from the rest of the facilities, the six clusters generally exhibited consistency across facility variables. Specifically, within a specific cluster, the 14 types of facilities exhibited similar levels of density and accessibility, demonstrating a consistent pattern of "high for high, low for low. (Figure 4.35, Figure 4.36)" For example, Cluster 1's facility density and accessibility were significantly lower than the city average, placing the overall curve at the bottom (top) of all clusters, reflecting a typical "global undermatch."

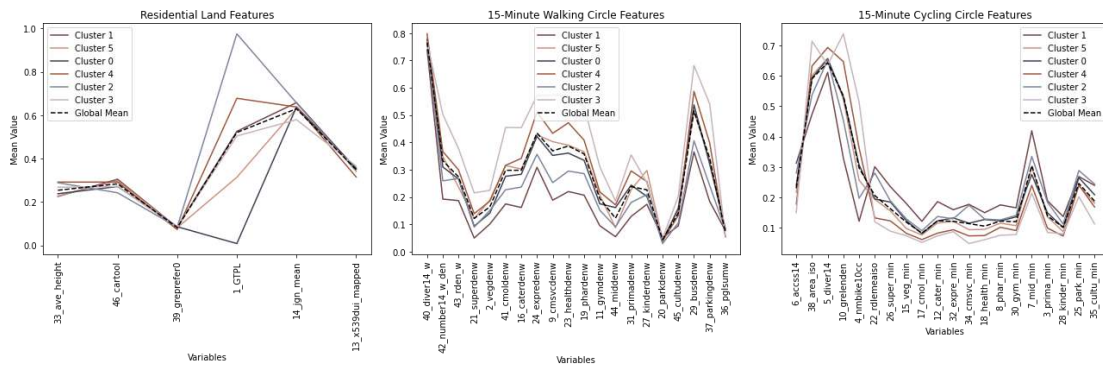


Figure 4.35 Comparison of six types of living circle features based on absolute mean values
(ordinate has been normalized)

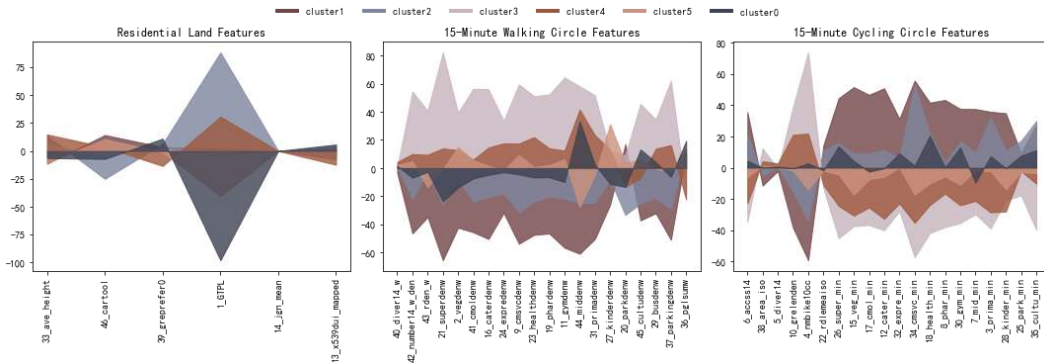


Figure 4.36 Comparison of six types of living circle characteristics based on city-level averages
(ordinate is percentage)

Comparison of six types of living circles (inter-cluster analysis): Clusters 0, 1, and 5 belong to low green travel living circles, while Clusters 2, 3, and 4 belong to high green travel living circles (Figure 4.35, Figure 4.36). We use two types of charts to reveal the core characteristics of each type of living circle. The study analyzes the core

characteristics of each type of living circle based on radar charts, either high values (corresponding to Zone 1) or low values (corresponding to Zone 3 in the Figure 4.34). Taking Cluster 3 with high values as an example, its normalized value for the variable *superdenw* (representing the density of supermarkets within a 15-minute walking radius, unit: per km²) is 1, indicating that this type of living circle has the highest supermarket density among all clusters. By displaying *superdenw* together with the other nine most representative variables through a radar chart, we can intuitively reflect the significant advantage of Cluster 3 in terms of convenient commercial resource allocation.

Cluster 0 is Near-rural Porous Living Circle (Figure 4.35). The living circle of Cluster 0 falls into the category of those located at the urban-rural interface. It was established relatively late, with a sparse road network, and lags behind in terms of large-scale urban facility construction (such as longer travel time to green spaces and cultural facilities, and lower density of supermarkets and sports facilities). It suffers from issues like complex structure, spatial fragmentation, and uneven resource allocation.

The living circle of Cluster 0 exhibits distinct characteristics across multiple structural and environmental variables. The ten most representative indicators include: travel preference index (*39_greprefer0*), residential type distribution (*13_x539dui_mapped*), public activity venue scale (*36_pglsumw*), average completion time of residential quarters (*14_jgn_mean*), diversity of facilities within the cycling circle (*5_diver14*), diversity of facilities within the walking circle (*40_diver14_w*), accessibility to green spaces (*25_park_min*), area of the cycling circle (*38_area_iso*), average length of main roads (*22_rdlemeaiso*), and accessibility to cultural facilities (*35_cultu_min*). The normalized values of these variables in Cluster 0 are all 1, indicating that this type of living circle has significant clustering characteristics in terms of facility coverage diversity, building completion dates, residential type structure, and transportation spatial pattern.

Cluster 0 corresponds to a living circle that exhibits significant disadvantages in terms of facility density and green travel level. Among its lowest 10 normalized indicators, the green travel proportion (GTPL) is the lowest among all types of living circles. This low value is attributed to the small number of trips. The second lowest is the density of supermarkets (*superdenw*). The remaining 8 indicators are at the downstream level, including the density of sports facilities (*gymdenw*), the density of parking facilities (*parkingdenw*), the density of community commerce (*cmoldenw*), the number of non-

motorized vehicles accessible to the city center (nmbike10cc), the density of community service centers (cmsvcdenw), the overall density of 14 types of facilities (number14_w_den), the density of catering facilities (caterdenw), and the density of pharmacies (phardenw). This indicates that the overall supply of facilities in this type of living circle is insufficient, lacking effective service facility support, and there is less land designated for services.

Cluster 1 is Hollow-core Living Circle. Cluster 1's living circle is "hollow", with extremely scarce facilities in the inner ring, scattered facility layout, and a lack of organization. It is a typical type of living circle with low-density facility distribution, poor pedestrian friendliness, and a very low degree of green travel.

The living circle corresponding to Cluster 1 exhibits the most disadvantageous performance in multiple dimensions of facility accessibility. The top 10 independent variables with the highest normalized values are all the shortest walking times to different types of facilities, including the arrival time to vegetable markets (15_veg_min), primary schools (3_prima_min), middle schools (7_mid_min), dining facilities (12_cater_min), leisure and entertainment facilities (32_expre_min), community service centers (34_cmsvc_min), medical facilities (18_health_min), pharmacies (8_phar_min), fitness facilities (30_gym_min), and kindergartens (28_kinder_min). These indicator values are generally higher in Cluster 1 compared to other types of living circles, indicating that residents within it find it more difficult to quickly reach various functional facilities necessary for daily life on a walking scale.

Cluster 1 corresponds to a living circle that exhibits a significant disadvantage in terms of facility supply density. Its lowest 10 normalized indicators are all related to facility density, including supermarket density (superdenw), number of non-motorized vehicle accessible city centers (nmbike10cc), middle school density (middenw), fitness facility density (gymdenw), community service center density (cmsvcdenw), parking facility density (parkingdenw), catering facility density (caterdenw), primary school density (primadenw), overall density of 14 types of facilities (number14_w_den), and medical service center density (healthdenw). For example, the total density of 14 types of facilities within a 15-minute walking living circle, denoted as number14_w_den, is 164.99 per square kilometer, with a city average of 308.97, a difference of 46.6%. This is a core characteristic of a hollow living circle. The generally low values of the above indicators in this cluster indicate that various daily service facilities in this type of living

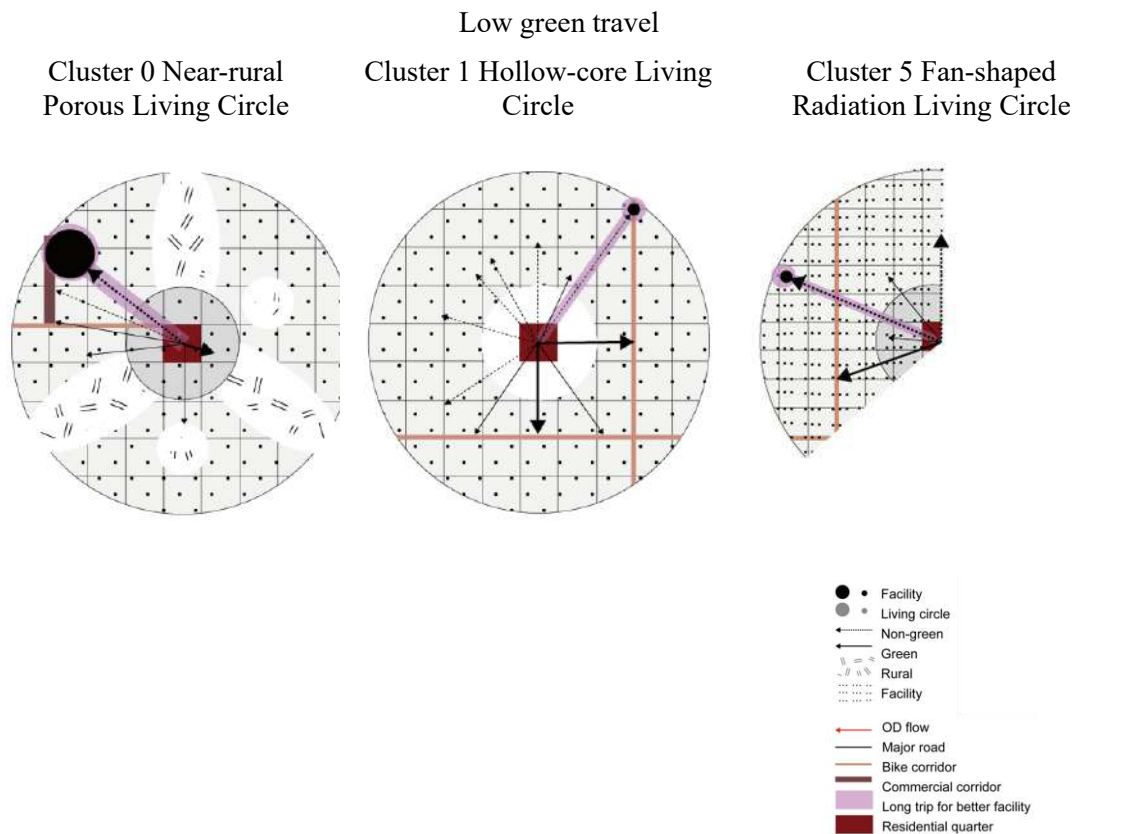
circle are sparsely distributed and insufficiently supplied.

Cluster 5 is Fan-shaped Radiation Living Circle. Cluster 5, with its relatively late establishment of living circles, proximity to open spaces, and uneven land use, exhibits certain vitality potential and pressure from transportation transformation. It reflects a spatial structure characteristic of abundant daily facility supply but insufficiently optimized green travel conditions.

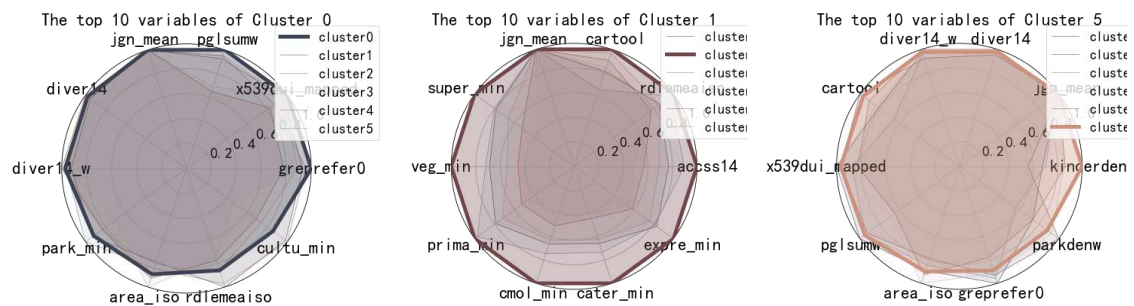
The living circle of Cluster 5 exhibits a unique pattern in terms of facility diversity, building structure, and residents' travel characteristics. The top ten variables with the highest normalized values are: kindergarten density (27_kinderdenw), average completion time of residential quarters (14_jgn_mean), diversity of cycling circle facilities (5_diver14), diversity of walking circle facilities (40_diver14_w), private car ownership rate (46_cartool), residential type structure (13_x539dui_mapped), public green space area within a 15-minute walking circle (36_pglsumw), and park density (20_parkdenw). These indicators collectively reflect that the living circle of Cluster 5 has high facility complexity in spatial functional organization, with high public green space area and park density, while also exhibiting a relatively new residential development pattern and significant motor vehicle dependency characteristics.

The living circle corresponding to Cluster 5 shows disadvantages in terms of the proportion of green travel and multiple facility indicators. Among the 10 poor normalized indicators, the walking accessibility of vegetable markets (veg_min), catering facilities (cater_min), and community service centers (cmsvc_min) is relatively low, indicating that daily facilities are close by. The number of city centers within the cycling circle (nmbike10cc), the density of secondary roads (rden_w), the density of supermarkets (superdenw), the density of middle schools (middenw), the density of primary schools (primadenw), the density of bus stops (busdenw), and the density of parking lots (parkingdenw) are all low. However, the accessibility of these facilities is higher than the city average, reflecting that there may be a "bias" in their spatial form and function, leading to lower densities of some facilities. Facilities that require a certain population size or commercial prospects to support (population/land use dependency), such as education, commerce, transportation, and parking, generally have lower densities; facilities that are crucial to residents' daily lives, such as vegetable markets, or have mandatory planning requirements, are guaranteed even in peripheral areas, thus maintaining a level comparable to the city average.

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Features with high value



Features with low value

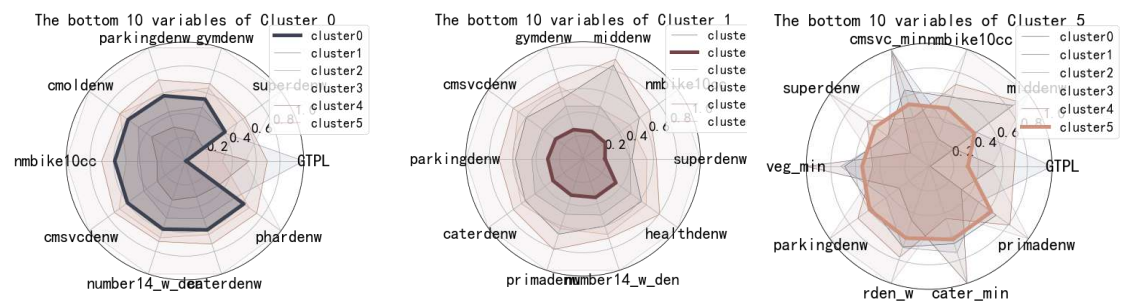


Figure 4.37 Three types of low-green travel living circles

Cluster 2 is Corridor-oriented TOD Living Circle (Figure 4.38). Residential land is often located along the main roads that extend outward from the edge of the city, and is commonly found in bus oriented areas with finger shaped development. The living service facilities are highly concentrated along the main roads or bus routes, especially around the 15 minute walking circle, forming a compact and highly connected layout. This type of living circle achieves the goal of supporting convenient living with less land by configuring high-intensity facilities along the way, and has high land use efficiency and green travel support capabilities. In contrast, the distribution of facilities within a 15 minute cycling circle is relatively sparse^[153].

The living circle of Cluster 2 exhibits a composite advantage in terms of green travel level and spatial form characteristics, with the most representative variables being: average completion time of residential quarters (14_jgn_cean), average height of buildings (33_ove_ceight), average length of main roads (22_rdlemeaiso), proportion of green travel in pedestrian circles (1_GTPL), diversity of cycling circle facilities (5-diver14), and diversity of pedestrian circle facilities (40-diver14w_). This type of living circle performs the best in terms of the proportion of green travel within a 15 minute walking circle, and is supported by tall buildings (with an average height of 22.87 meters in residential quarters) and mature built environments. At the same time, it has functional diversity, forming a typical efficient living circle that combines compactness, connectivity, and sustainable travel. It represents a development form of goal oriented livable communities, with overall superiority in promoting green travel mechanisms and spatial organization models.

The 10 indicators with lower normalized values in Cluster 2 are: the number of city centers within the cycling circle (nmbike 10cc), the density of supermarkets (super denw), the density of community service centers (cmsvdenw), the density of parking facilities (parkingdenw), the density of middle schools (middenw), the density of fitness facilities (gymdenw), the density of community commercial outlets (cmoldenw), the density of primary schools (primedenw), the overall density of 14 types of facilities in the pedestrian circle (number 14w__den), and the density of medical facilities (healthdenw), all ranking second to last among the six types of living circles, indicating that this type of living circle still has shortcomings in terms of multi type facility density. Observing the facility density and accessibility of the 15 minute walking circle, it was found that the accessibility of most of the facilities in Cluster 2 (excluding 4 out of 14 categories: green space

accessibility (25_cark-min), cultural facility accessibility (35_cultu-min), community service center accessibility (34_cmsvc-min), and primary school accessibility (3_prima_min)) is at a normal level, indicating that although the density is low, services can be relatively easily obtained.

Cluster 3 is Poly-kernel Living Circle. Residential land is located in the central area of the city, with multiple city center nodes distributed within a 15 minute cycling and living circle, forming a multi-core functional agglomeration pattern. The facilities are evenly distributed along the regular grid road network, with an orderly structure and wide coverage, reflecting good road connectivity and spatial accessibility. This type of living circle integrates high-density development, high functional mixing, and high service supply, demonstrating the composite advantages of high agglomeration, convenient travel, and convenient living. It is a typical functional urban core living circle.

Cluster 3 performs the best on all ten key independent variables among all clusters: it has the largest 15 minute cycling living circle area (area_iso), the densest cycling lane density (greyenden) (3095.85 meters per kilometer) and secondary road density (rden-w) (4.03 meters per kilometer), and the highest number of central nodes (nmbike 10cc) (3.11); At the same time, the total density of 14 types of facilities within its 15 minute walking circle (number 14w__den) (477.45 per square kilometer), the density of supermarkets (super denw), vegetable markets (vegdenw), community commercial density (cmoldenw), catering density (caterdenw), and leisure and entertainment facility density (exredenw) have all reached their peak.

The 10 lowest normalized indicators in Cluster 3 are all pedestrian accessibility indicators, and they are the lowest among the six types of living circles: community service centers (cmsvc_min), supermarkets (super_in), catering facilities (cather_min), medical facilities (health_in), vegetable markets (veg_in), community commercial outlets (cmol_in), pharmacies (phar_min), primary schools (prima_min), cultural activity facilities (cultu_in), and fitness facilities (gym_min), indicating that multiple types of facilities in this living circle are highly accessible and residents can easily access services.

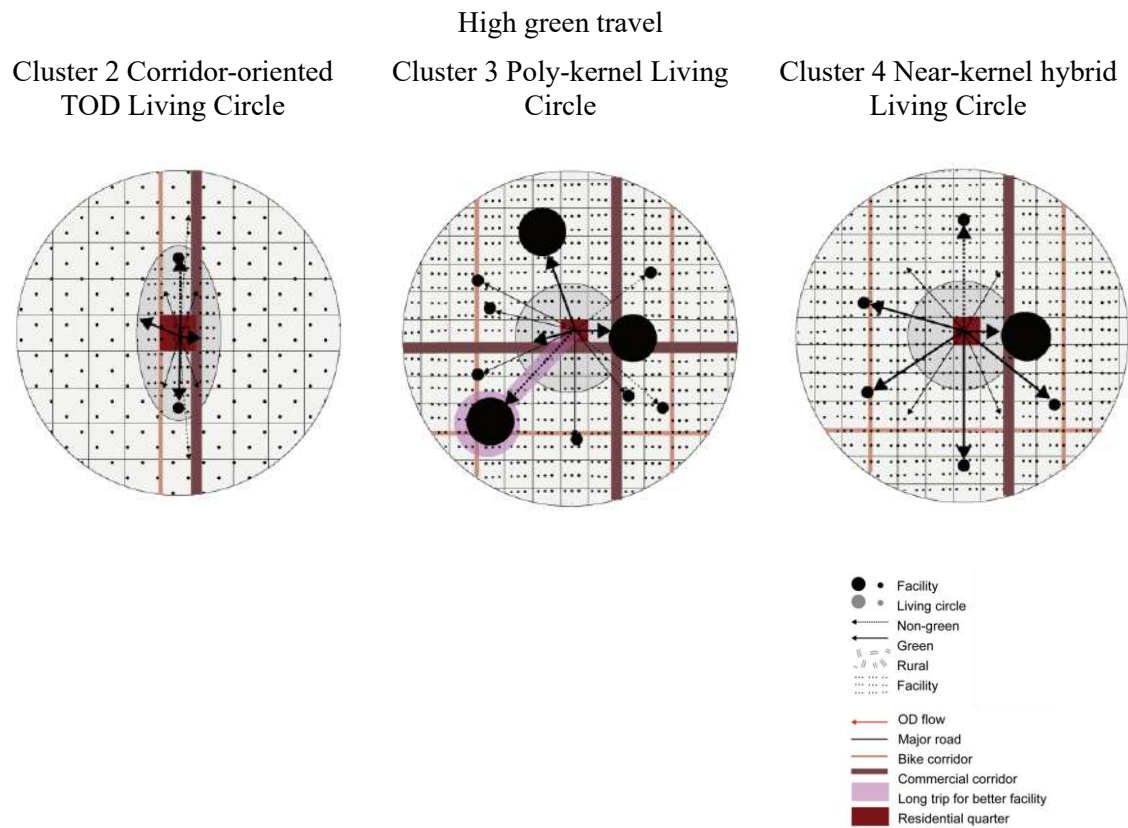
Cluster 4 is Near-kernel hybrid Living Circle. Residential land is mostly distributed near the city center, close to the city center nodes, and some nodes even fall within a 15 minute walking circle. The distribution of facilities within the living circle is relatively balanced, with a wide coverage and diverse types of functional facilities within the 15 minute cycling circle, reflecting high spatial accessibility and functional mix. In terms of

spatial structure, travel conditions, and facility configuration, this type of living circle combines the convenience of the central area with the accessibility of the surrounding area, and has strong comprehensiveness and coordination.

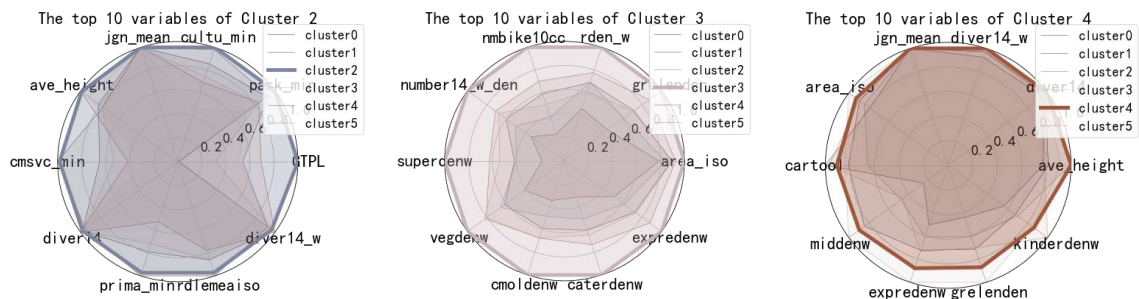
The two indicators of Cluster 4's living circle are the highest values among the six types of living circles, namely the diversity of cycling circle facilities (5-diver14) (1.47) and the diversity of walking circle facilities (40-diver14w_) (1.45). The other top ten independent variables with the highest normalized values include: average completion time of residential quarters (14_jgn_cean), cycling track density (10_grelenden), average building height (33_ave_height), cycling living circle area (38_rea_iso), private car ownership rate (46_cartool), middle school density (44_middenw), leisure and entertainment facility density (24_preddenw), and kindergarten density (27_kindergarten). These indicators reflect that the overall living circle of Cluster 4 exhibits high building strength, mature built environment, and good spatial coverage capability, with a functional configuration that meets the diverse needs of education, entertainment, and transportation.

The 10 lowest indicators in Cluster 4 are: Community Service Centers (cmsvc_min), Catering Facilities (cater_min), Vegetable Markets (veg_in), Medical Facilities (health_in), Community Commercial Outlets (cmol_in), Supermarkets (super_in), Primary Schools (prima_min), Kinder_min, Fitness Facilities (gym_min), and Comprehensive Facility Accessibility (accss14). These accessibility indicators are all ranked first or second in the six living circles, indicating high accessibility.

CHAPTER 4 CORRELATION BETWEEN ALL-TYPE GREEN TRAVEL AND FACILITY LAYOUT



Features with high value



Features with low value

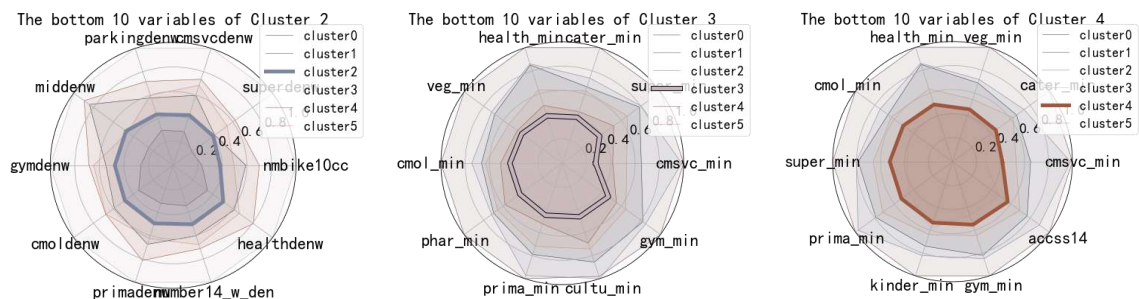


Figure 4.38 Three types of living circles for high green travel

4.4.4 Density and accessibility as core facility layout dimensions behind high–low cluster differentiation

In the previous section, the study analyzed the core characteristics of various living circles, either high values (corresponding to zone 1) or low values (corresponding to zone 3 in Figure 4.34). Different from the layout characteristics of living circle facilities, the layout characteristics of green travel related facilities can analyze the facility layout characteristics corresponding to the degree of green travel, which is achieved by comparing SHAP values.

For example, the primary school in this living circle is very close, and its accessibility falls within the green travel promotion zone, which is a characteristic that leads to its green travel (corresponding to Figure 4.34 zone 3-B). The density of sports facilities in this living circle is high. Although there is a correlation between the density of sports facilities and green travel, the high density of sports facilities exceeds the threshold and is not in the promotion zone of green travel. Therefore, this feature is the factor that leads to its poor green travel (corresponding to zone 1-A).

Therefore, in order to evaluate whether a certain feature is conducive to green travel, it should not be based on the low height of the feature itself, but should be tested whether the feature is in the green travel optimal range, which can be achieved by comparing SHAP values. The SHAP value of the feature is positive, corresponding to zone B in the green travel optimal range; The SHAP value of the feature is negative, in the green travel suppression interval, corresponding to zone A in Figure 4.34.

For the three types of living circles with a high proportion of green travel, this study identifies ten key variables with positive SHAP values and variable mean values in the optimal range, analyzes the planning methods for green travel in this type of living circle, and provides ideas for other cities and samples. For the three types of living circles with a low proportion of green travel, identifying key variables with negative SHAP values and variable mean values outside the promotion range can guide policy makers to optimize facilities and intervene in the environment according to local conditions in different types of living circles.

For the three types of living circles with a high proportion of green travel:

Cluster 2 has a high proportion of green travel in the living circle, with high proximity to green travel and reasonable road conditions being key factors. For example, greyenden, veg_min, and vegdenw are all in the range that can promote the proportion of

green travel (03112.59), (2.05,+∞), and (7.73, 14.88).

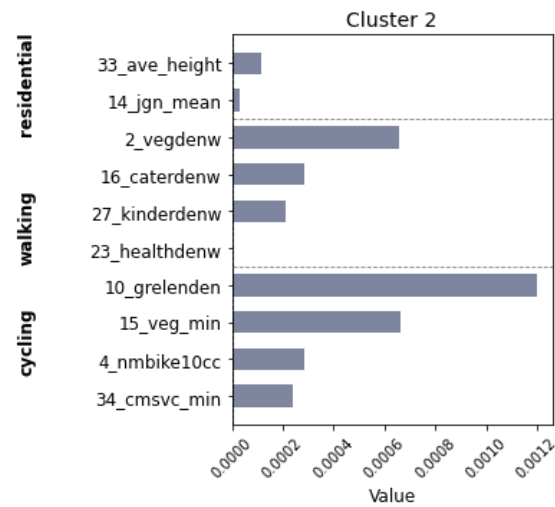


Figure 4.39 Mean of key factors for green travel in Cluster 2 living circle

Table 4.9 Mean SHAP values of key factors for green travel in Cluster 2 living circles and comparison with optimal ranges

Rank_Feature	Rank	cluster2 SHAP	Category	cluster2 status	Positive range	Positive heak
33_ave_height	33	0.00011712	resident ial	22.87	(19.08,+∞)	80
14_jgn_mean	14	3.29041E-05	resident ial	2007.63	(2000,2011)	2004
2_vegdenw	2	0.000660023	walkin g	13.21	(7.73,14.88)	14
16_caterdenw	16	0.000283675	walkin g	59.24	(0,81.03) ∪ (215,+∞)	65
27_kinderdenw	27	0.000210193	walkin g	1.47	(1.31,3.71)	3
23_healthdenw	23	4.48821E-06	walkin g	8.69	(0,14.41)	10
10_grelenden	10	0.001200778	cycling	1891.26	(0,3112.59)	2500
15_veg_min	15	0.000663523	cycling	4.34	(2.05,+∞)	2.5
4_nmbike10cc	4	0.000284023	cycling	1.19	(0,3.2)	1
34_cmsvc_min	34	0.00023863	cycling	11.24	(2.53,+∞)	20

Cluster 3 has a high proportion of green travel in the living circle, and good location

and corresponding high density and accessibility are key factors. For example, greytenden, nmbike 10cc, and mid-min are all in the range that can promote the proportion of green travel (03112.59), (0,3.2), and (8,16.25).

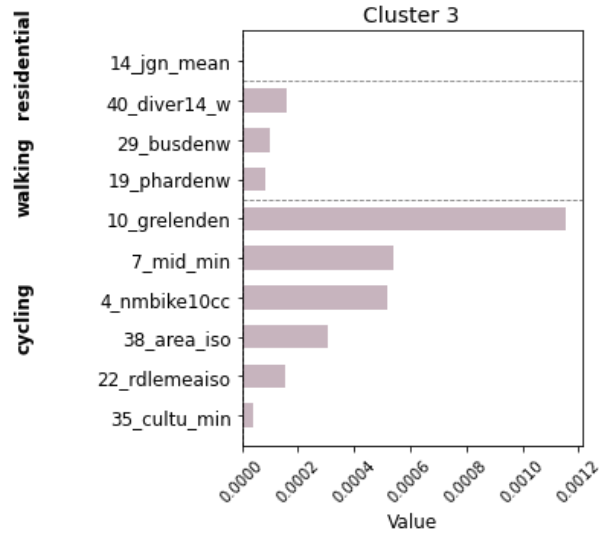


Figure 4.40 Mean of key factors for green travel in Cluster 3 living circle

Table 4.10 Mean SHAP values of key factors for green travel in Cluster 3 living circles and comparison with optimal ranges

Rank_Feature	Rank	cluster 3 SHAP	Category	cluster3_status	Positive range	Positive heak
14_jgn_mean	14	8.83979E-06	residential	2004.81	(2000,2011)	2004
40_diver14_w	40	0.000161259	walking	1.4	(1.4,1.65)	1.6
29_busdenw	29	9.90397E-05	walking	12.66	(8.08,12.76)	10
19_phardenw	19	8.37249E-05	walking	21.16	(14.15,35.36)	20
10_grelenden	10	0.001155368	cycling	3095.85	(0,3112.59)	2500
7_mid_min	7	0.000537877	cycling	10.73	(8,16.25)	14
4_nmbike10cc	4	0.000519301	cycling	3.11	(0,3.2)	1
38_area_iso	38	0.000304518	cycling	26170017.6	(16316337.66, 21000000) ∪ (23000000, 30626708.62)	27000000
22_rdlemeaiso	22	0.000151929	cycling	327.25	(326.51,+∞)	360
35_cultu_min	35	3.77948E-05	cycling	7.21	(0,7.3) ∪ (15,+∞)	5

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Cluster 4 has a high proportion of green travel in the living circle, and the location near the city center and balanced facility layout make this type of sample have reasonable diversity, density, and accessibility. For example, Kinderdenw, Grelenden, and Vegezmin are all in the range that can promote the proportion of green travel (1.31, 3.71), (03112.59), and (2.05,+ ∞).

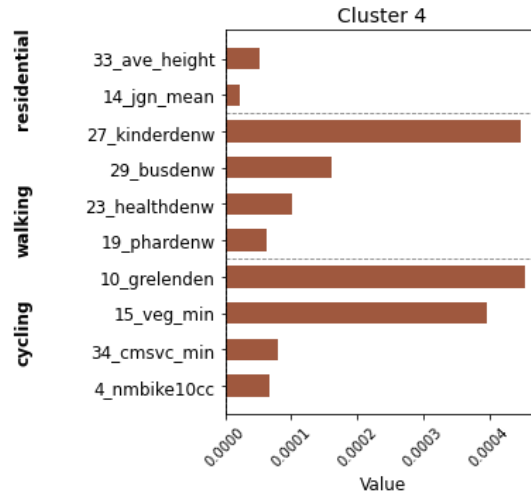


Figure 4.41 Mean of key factors for green travel in Cluster 4 living circle

Table 4.11 Mean SHAP values of key factors for green travel in Cluster 4 living circles and comparison with optimal ranges

Rank_Feature	Rank	cluster4 SHAP	Category	cluster4 status	Positive range	Positive peak
33_ave_height	33	5.28999E-05	residential	23.11	(19.08,+ ∞)	80
14_jgn_mean	14	2.22937E-05	residential	2006.96	(2000,2011)	2004
27_kinderdenw	27	0.00044853	walking	1.81	(1.31,3.71)	3
29_busdenw	29	0.000161402	walking	10.71	(8.08,12.76)	10
23_healthdenw	23	0.000100481	walking	13.91	(0,14.41)	10
19_phardenw	19	6.24547E-05	walking	15.83	(14.15,35.36)	20
10_grelenden	10	0.000454482	cycling	2698.34	(0,3112.59)	2500
15_veg_min	15	0.000395917	cycling	2.76	(2.05,+ ∞)	2.5
34_cmsvc_min	34	8.09102E-05	cycling	4.75	(2.53,+ ∞)	20
4_nmbike10cc	4	6.72457E-05	cycling	2.18	(0,3.2)	1

For the three types of living circles with a low proportion of green travel:

Cluster 0 Living circle has the lowest proportion of green travel among all clusters. Multiple factors contribute to this result, including low accessibility, low density, and low connectivity. Attention should be paid to x539duiumapped, prima_min, and accss14. The ideal interval can refer to (0,2.7), (2.1,8.56), and (0,5.35) to promote green travel.

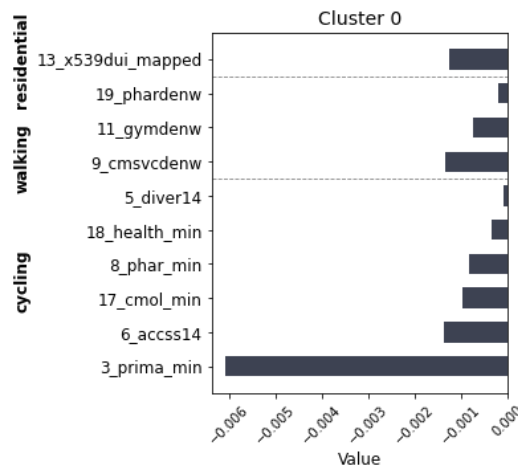


Figure 4.42 Mean of Factors to be Improved for Green Travel in Cluster 0 Living Circle

Table 4.12 Mean SHAP values of key factors for green travel in Cluster 0 living circles and comparison with optimal ranges

Rank_Feature	cluster0 SHAP	3 Circles	6 Interaction Dimensions	cluster0 status	Positive range	Positive heak
13_x539dui_mapped	0.001259514	residential	Attitude	2.91	(0,2.7)	2
19_phardenw	0.000188327	walking	Density	12.97	(14.15,35.36)	20
11_gymdenw	-0.00073053	walking	Density	5.25	(0,4.04)	4
9_cmsvcdenw	0.001330961	walking	Density	4.21	(6.41,+∞)	12
5_diver14	-6.85801E-05	cycling	Diversity	1.44	(0,1.4)	1.4
18_health_min	0.000340513	cycling	Accessibility	4.95	(0,1.89)	0
8_phar_min	0.000828591	cycling	Accessibility	3.75	(0,2.2)	0
17_cmol_min	0.000951256	cycling	Accessibility	1.57	(0,1.08)	0
6_accss14	0.001360456	cycling	Accessibility	8.41	(0,5.35)	0
3_prima_min	0.006078013	cycling	Accessibility	10.44	(2.1,8.56)	5

CHAPTER 4 CORRELATION BETWEEN ALL-TYPE GREEN TRAVEL AND FACILITY LAYOUT

Cluster 1 has a low proportion of green travel in the living circle, with low density and low accessibility being key factors. Attention should be paid to 13-x539duimmapped, prima_min, and primadenw. The ideal range can refer to (0,2.7), (2.1,8.56), and (1.75,+∞) to promote green travel.

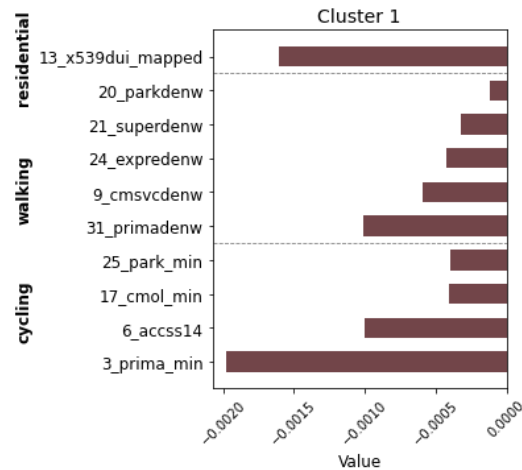


Figure 4.43 Mean of factors to be improved for green travel in Cluster 1 of the living circle

Table 4.13 Mean SHAP values of key factors for green travel in Cluster 1 living circles and comparison with optimal ranges

Rank_Feature	cluster1 SHAP	Category 3 Circles	6 Interaction Dimensions	cluster1 status	Positive range	Positive heak
13_x539dui_mapped	-0.00160831	residential 1	Attitude	2.81	(0,2.7)	2
20_parkdenw	0.000116336	walking	Density	1.3	(0,0.36)	0.18
21_superdenw	0.000322935	walking	Density	0.39	(3.43,+∞)	9
24_expredenw	-0.00042424	walking	Density	5.52	(11.57,+∞)	18
9_cmsvcdenw	0.000593418	walking	Diversity	2.03	(6.41,+∞)	12
31_primadenw	0.001013142	walking	Accessibility	0.4	(1.75,+∞)	3.4
25_park_min	0.000398594	cycling	Accessibility	12.57	(0,8.89)	0
17_cmol_min	0.000406745	cycling	Accessibility	2.36	(0,1.08)	0
6_accss14	0.001004509	cycling	Accessibility	10.93	(0,5.35)	0
3_prima_min	0.001975669	cycling	Accessibility	13.21	(2.1,8.56)	5

Cluster 5 has a low proportion of green travel in the living circle, and the occupation of residential land by other land uses is a key factor. Attention should be paid to x539duiumapped, prima_min, and primadenw. The ideal range can refer to (0,2.7), (2.1,8.56), and $(1.75, +\infty)$ to promote green travel.

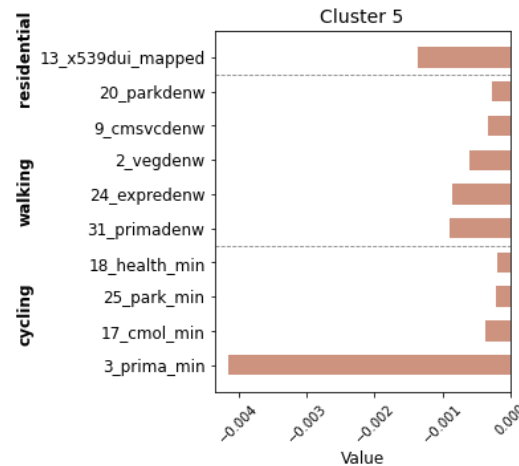


Figure 4.44 Mean of factors to be improved for green travel in Cluster 5 of the living circle

Table 4.14 Mean SHAP values of key factors for green travel in Cluster 5 living circles and comparison with optimal ranges

Rank_Feature	cluster5 SHAP	3 Circles	6 Interaction Dimensions	cluster5 status	Positive range	Positive heak
13_x539dui_mapped	-0.001365461	residential	Attitude	2.81	(0,2.7)	2
20_parkdenw	-0.000265442	walking	Density	1.15	(0,0.36)	0.18
9_cmsvcdenw	-0.000334816	walking	Density	4.82	(6.41,+∞)	12
2_vegdenw	-0.000592494	walking	Density	16.52	(7.73,14.88)	14
24_expredenw	-0.00084923	walking	Density	7.99	(11.57,+∞)	18
31_primadenw	-0.000886282	walking	Density	0.77	(1.75,+∞)	3.4
18_health_min	-0.00019146	cycling	Accessibility	3.7	(0,1.89)	0
25_park_min	0.000215138	cycling	Accessibility	11.17	(0,8.89)	0
17_cmol_min	0.000368262	cycling	Accessibility	1.49	(0,1.08)	0
3_prima_min	0.004156793	cycling	Accessibility	9.51	(2.1,8.56)	5

4.4.5 Typical living circles

In order to conduct in-depth analysis of various living circles, the author selected a sample from each type of living circle for field research and empirical analysis. The sample space distribution is as follows, with red numbers representing sample codes. Please refer to the table for the types they represent. Regarding facility symbols, the six categories of low-density and low reachable facilities are represented by special symbols (▲), while the other ten categories are visualized using a unified symbol (●) to distinguish between large-scale scarce facilities and small-scale non scarce facilities. Please refer to section 4.1.4 for specific reasons. Although community service centers are also non scarce facilities, they are visualized in black squares (■) because of the uniqueness of such facilities for residential quarters.

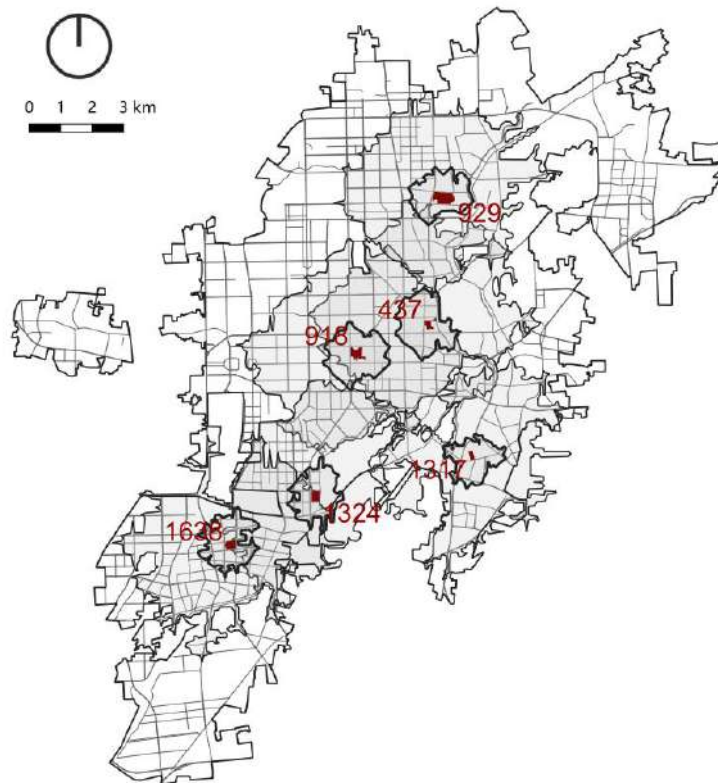


Figure 4.45 Spatial distribution of six types of living circles

(1) Cluster 0: Near-rural Porous

Representative: 1317 South Factory Building Community, a 4-story residential quarter combining urban and rural areas, surrounded by villages or mixed with rural bungalows, with lush trees and winding roads, composed of wide roads combined with

local narrow roads. The commercial services within the 15 minute walking circle have formed a scale, even including Wanbo Yuan International Ceramic Building Materials Home Living Plaza, but the quality is poor. For example, some shops have been transformed from the first floor of residential buildings. Therefore, residents choose to travel more to the small mountain wholesale market and the old department store in the city center, which are about 3km outside the 15 minute walking circle (at the edge of the 15 minute cycling circle), for shopping. Along the road, artificial buildings and natural agriculture and forestry intertwine, with low density and height of artificial buildings, mainly serving the automotive industry.

(2) Cluster 1 Hollow-core

Representative: 1324 Vanke Hongjun South District, a 400-meter square residential quarter with a total of 8 3-story villas, located in the urban edge new district residential quarter. The occupancy rate is below 30%. Due to the low population density, there are no kindergartens, neighborhood committees, or other service facilities within the plot. Many of the ground floor shops around the plot have not yet opened, with less than 10 shops in operation. The residential quarter is isolated from the outside world, and the land within the 15 minute walking circle is either idle, under construction, or abandoned. Residents need to go outside the 15 minute walking circle to obtain daily services. Although the residential quarter is small in scale, it is generally not conducive to residents' daily life and travel. Residents show a preference for low green travel and often use cars for transportation.

(3) Cluster 5 fan-shaped radiating layout

Representative: 437 Northwest Xinlou Community, a 6-story residential quarter located next to the city center. The residential quarter is surrounded by three parks (Dachengshan Park, Labor Park, Fenghuangshan Park), and there are many large-scale public welfare facilities within a 15 minute walking circle (Workers' Hospital, Elderly Cadre Activity Center, Mass Art Museum, Xibeijing Primary School, Beijing Institute of Technology), resulting in fewer small-scale, especially commercial facilities and low richness of commercial formats, which affects the convenience of daily life. Within the 15-minute cycling circle, there is a downtown commercial area, including 7 large supermarkets such as Sun City. The residential quarter within a 15-minute walk has a low density of roads and weak advantages in daily life services. The educational format mainly serves the school community, while there are relatively few formats that serve the

daily life of local residents.

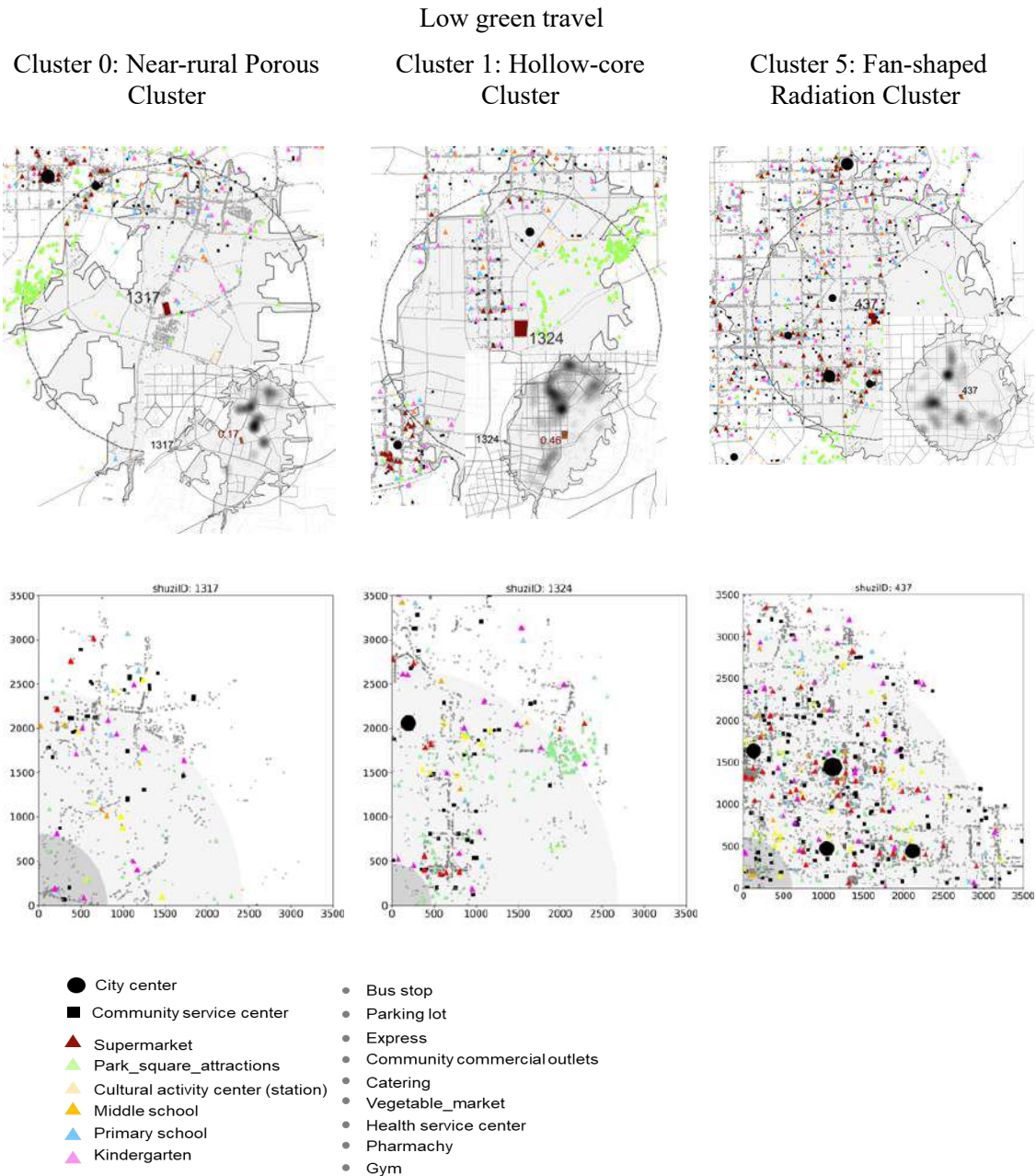


Figure 4.46 Layout of low green travel sample facilities, travel agglomeration, and quadrant diagram

(4) Cluster 2 TOD Unidirectional Along Road Expansion Layout

Representative: 1638 Rongsheng Lake Lishe Baihe Garden, located far from the city center, on the west side of the main road in the new urban area on the edge of the city. It is a 30-story high-rise building, but under the TOD development strategy, the facility density is high within a 15-minute walking circle, distributed along the main road and

extending north to south. The main road on the east side of the residential quarter is the bus corridor, and there are two bus stops on the main road section where the residential quarter is located, which drives the commercial development within the corridor. Although the facilities within the 15-minute cycling circle are sparse, the facilities within the 15-minute walking circle are already sufficient and diverse, such as supermarkets, art galleries, and banks. Residents mainly rely on green travel, and the shape of the 15-minute walking circle is a narrow north-south extending ellipse.

(5) Cluster 3 Multikaryotic Layout

Representative: 918 Army Anli Shangzuo Garden, a residential quarter in the downtown business district, a 6-story old community, adjacent to the busiest Xinhua Road and Antique City, which are the earliest origins of Tangshan. Within a 15-minute cycling circle, there are multiple downtown nodes (7 supermarket clusters and old department stores). The residential and commercial areas are integrated, with connected internal and external roads and abundant underground businesses along the street. Some of the community level roads are open roads, full of street vendors and vitality along the street. In addition, the street scale (residential quarter level roads have high density, about 240 meters long) is pleasant, and the proportion of pedestrians is high.

(6) Cluster 4: Near Kernel Hybrid Layout

Representative: 929 Century Longting+Xinjing Building, a 6-story residential quarter near the city center with a high proportion of green travel and low degree of motorization. Although it is a closed access control community, due to the complete facilities of community committees and kindergartens within the residential land, the underground shops along the street within a 15-minute walking circle are rich and diverse, and the convenience market provides vibrant services all day long. The 15-minute cycling circle also includes the city center node, which is close to the Ocean City Shopping Center, Department Store People's Shopping Plaza, and International Convention and Exhibition Center in the city center (only about 1000m away), making travel convenient. The distance between the main roads within the 15-minute cycling living circle in the residential quarter is relatively small, about 400m. The road density in the residential quarter is high, and the block scale is pleasant, with a comfortable walking environment.

High green travel

Cluster 2 Corridor-oriented
TOD Living Circle

Cluster 3 Poly-kernel Living
Circle

Cluster 4 Near-kernel hybrid
Living Circle

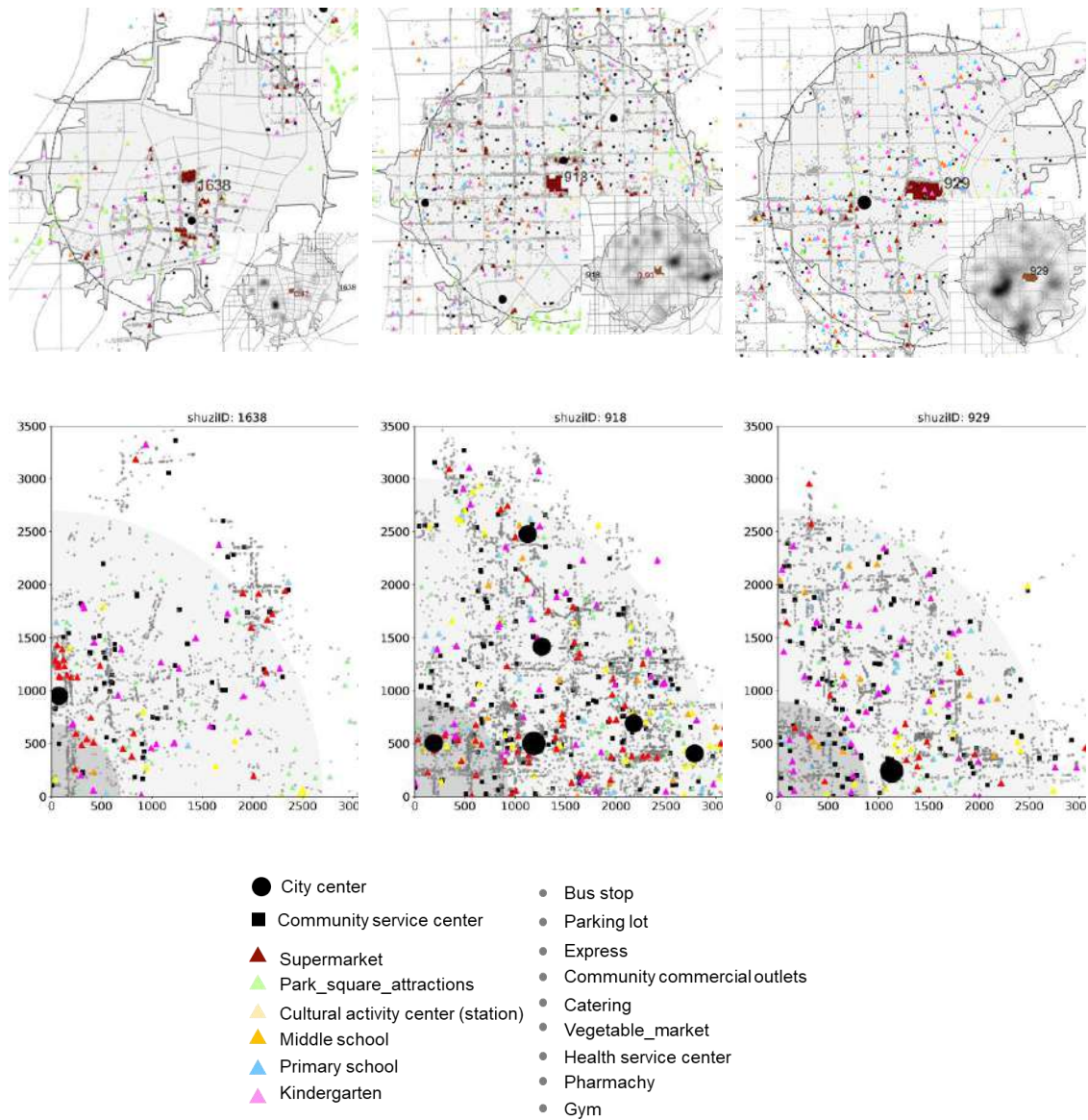


Figure 4.47 Layout of high green travel sample facilities, travel agglomeration, and quadrant diagram

4.5 Research validation

4.5.1 Facility importance verification based on spatial status

The previous text obtained the importance of independent variables for green travel. The density and accessibility of shopping facilities are both important, while the accessibility of educational facilities is more important. The density of health and leisure facilities is more important, which is related to the current layout of facilities and the logic

of travel choices. Taking the hollow living circle 1324 with low green travel level and the multi core living circle 918 with high green travel level as examples, the current layout of facilities is classified and visualized. It is found that educational facilities are distributed in a point like low-density pattern and are far away from residential quarters; Leisure and health facilities are densely distributed in clusters, with a moderate distance from residential quarters; And shopping facilities are densely distributed along the street, close to residential quarters. The nuclear density of the four types of facilities [verified using nuclear density instead of 15-minute walking circle facility density, firstly because the research process used 15-minute walking circle facility density, which would be repeated if used again, and secondly because nuclear density is more intuitive.] Ranking: shopping category (3314.701 POIs/km²)>health category (243.28 POIs/km²)>leisure category (144.741 POIs/km²)>education category (30.159 POIs/km²), consistent with the ranking in Figure xxx, indicating that "high density" corresponds to "high importance", proving the validity of the importance result.

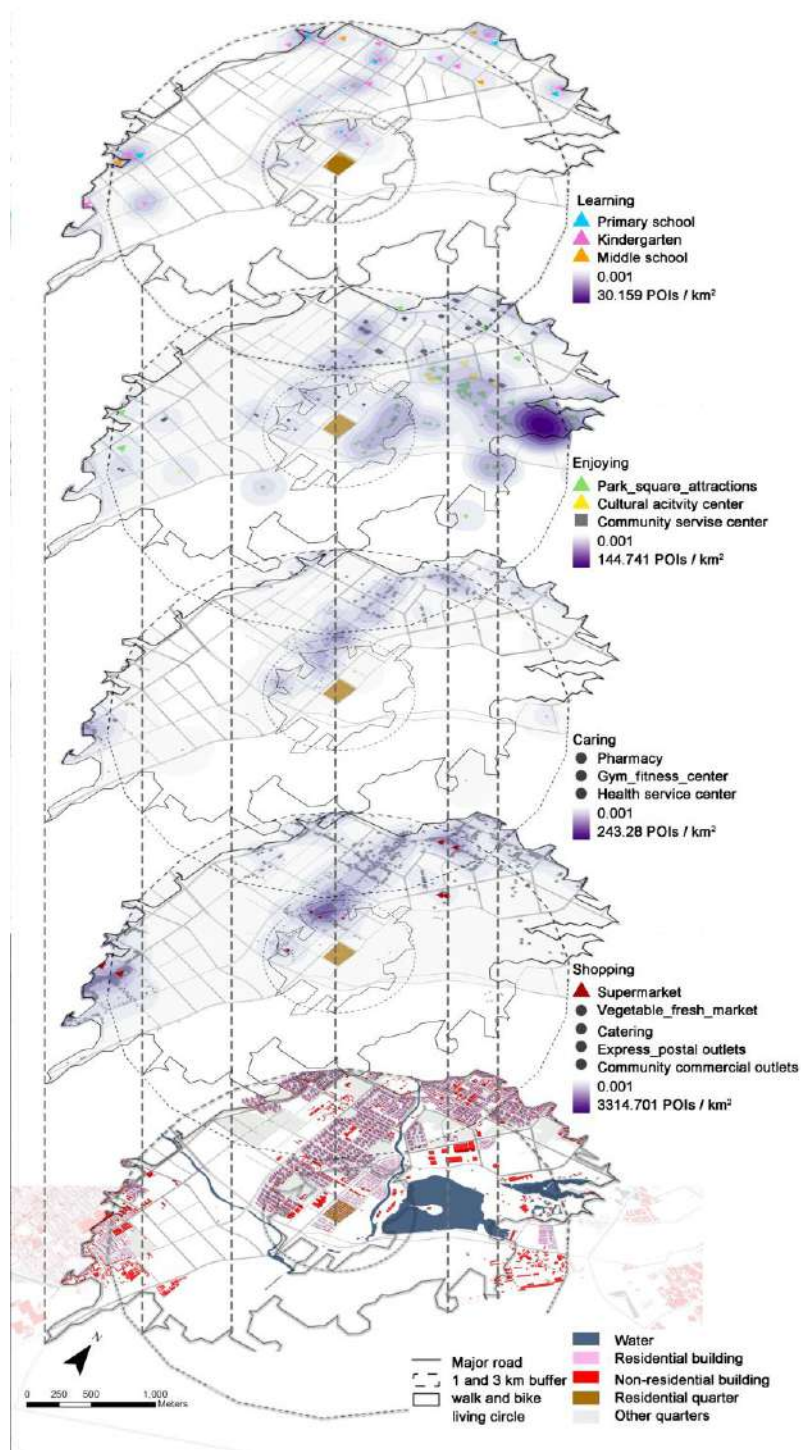


Figure 4.48 Current facility layout of hollow-core living circle 1324 with low green travel level

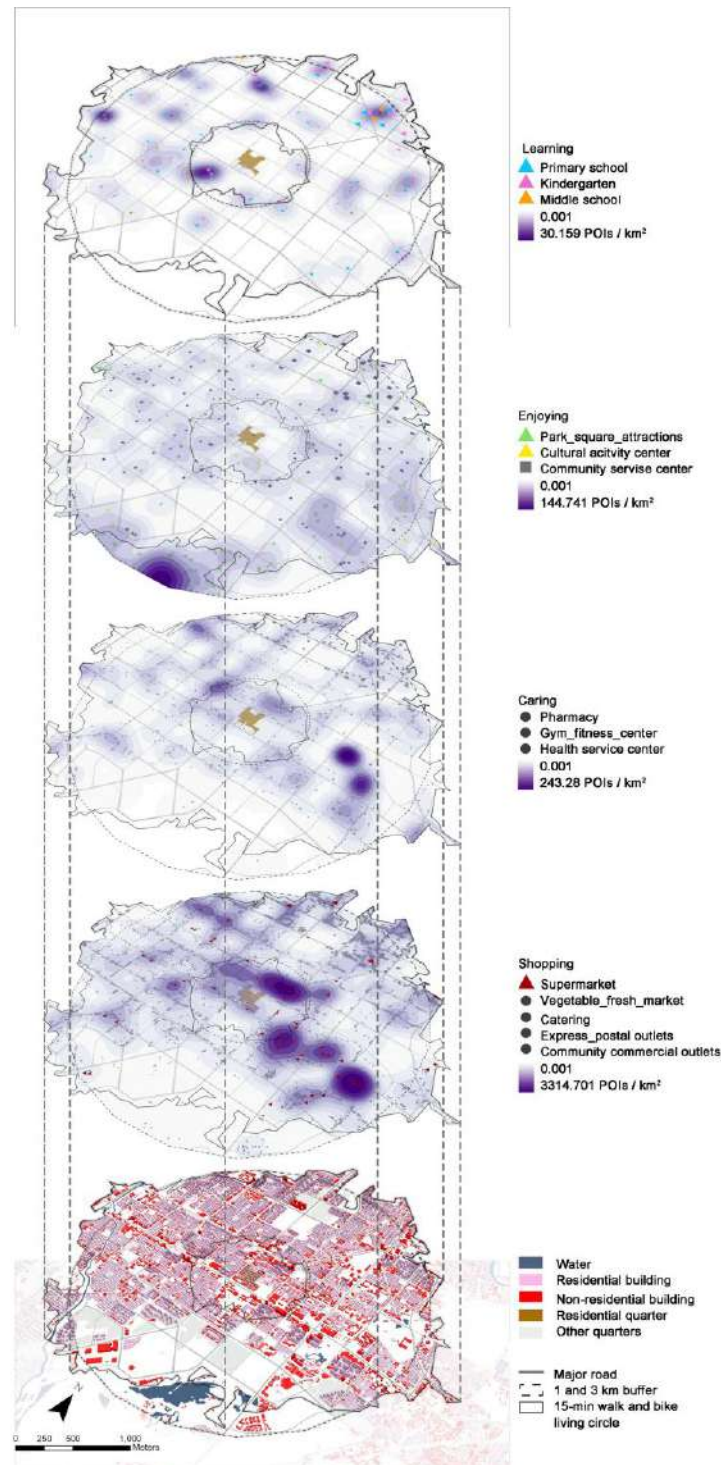


Figure 4.49 Current facility layout of poly-kernel living circle 918 with high green travel level

4.5.2 Facility importance verification based on requirement map

As found earlier, if a certain type of facility has high-density layout, high-frequency usage demand, and strong substitutability for travel purposes, its density has a significant

promoting effect on green travel. In the ranking of the importance of green travel in 14 types of facilities, the vegetable market and fresh food supermarket are the most important, accounting for 11.7%, while cultural activity centers or stations are the least important, accounting for 3.9%, reflecting the indispensable role of vegetable markets in daily life and the low frequency of cultural activities. This article uses 14411 questionnaire data from the "2021 Urban Physical Examination Resident Satisfaction Survey" to draw a demand map, reflecting residents' needs for facility supplementation and updates, comparing the status of facilities, and verifying the importance of facilities. Questionnaire suggestions include: "There is no supermarket market near the community, which is not very convenient"; Add more entertainment facilities instead of fewer cultural and entertainment facilities.

Based on the current POI, there are a total of 1759 vegetable markets and fresh supermarkets, as well as 118 cultural activity centers or stations; Among the improvement suggestions put forward by residents, there are a total of 517 suggestions related to "vegetable markets, fresh supermarkets" and 38 suggestions related to "cultural activity centers or stations". The results indicate that fresh supermarkets in vegetable markets are more densely distributed than cultural activity centers or stations. However, even if fresh supermarkets in vegetable markets are densely distributed, residents still believe that the supply of facilities is insufficient or the quality needs to be improved. Moreover, more feedback is given to fresh supermarkets in vegetable markets, indicating that residents rely more on fresh supermarkets in vegetable markets for their daily lives. This proves that the conclusion that "fresh supermarkets in vegetable markets are more important for green travel than cultural activity centers or stations" is valid.

CHAPTER 4 CORRELATION BETWEEN ALL-TYPE GREEN TRAVEL AND FACILITY LAYOUT

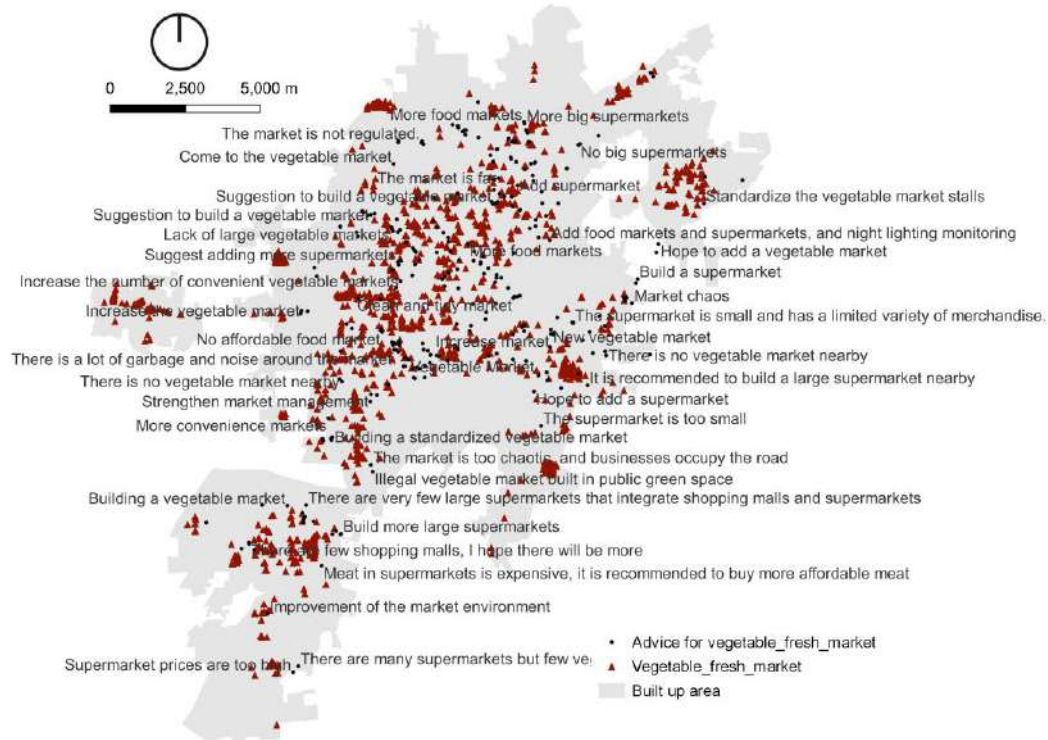


Figure 4.50 Demand map for vegetable market

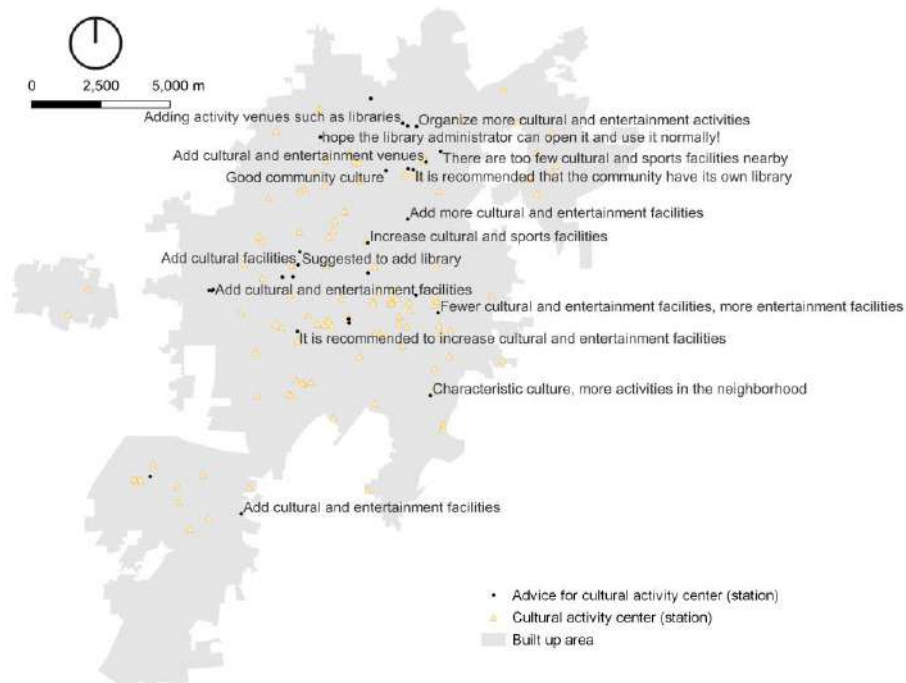


Figure 4.51 Demand map for cultural activity centers (stations)

4.6 Summary

This chapter analyzes the influencing mechanism and path of 46 independent variables on the green travel proportion in all categories, comprehensively examines the rules of importance, driving dimensions and optimal ranges, and identifies six types of living circles with different gradients in the degree of green travel.

Regression and SHAP analysis revealed that green travel is driven by a synergistic combination of factors, with accessibility and density being the core influencing factors. Accessibility accounted for 46.4% of the weight and was generally negatively correlated, with closer distance associated with a higher proportion of green travel. Density contributed 33.3%, demonstrating a significant threshold effect: too low a value leads to a lack of service, while too high a value leads to redundant facilities. For example, the highest proportion of green travel occurs when the walking distance to a courier service is 0–1.98 minutes, and the number of vegetable markets is 7.7–14.9 per km².

Facility types exhibit significant differences in importance and driving factors. A comparison of functional types reveals that vegetable markets and primary schools are the most important single-category facilities; shopping facilities have the strongest impact on green travel (38.9%), followed by education (23.9%) and health (23.3%); leisure facilities have a weaker impact (14.0%). Educational facilities are primarily driven by accessibility, while health and leisure facilities rely more on density, and shopping facilities exhibit a dual driving force. This difference stems from the inherent relationship between facility distribution, function, and travel frequency: educational activities have fixed needs and single-point satisfaction, while leisure activities require high frequency and diversity, while shopping and health trips combine proximity, convenience, and high-density attraction.

Clustering results identify six types of living circles with varying levels of green travel. The three types of high green travel include: 1. Poly-kernel Living Circle, a regular road network, and balanced facility distribution; 2. Near-kernel hybrid Living Circle, combining central convenience with peripheral coordination and high facility accessibility; 3. Corridor-oriented TOD Living Circle, with facilities clustered along main roads, forming "corridor-style" green travel spaces. The three types of low green travel include: 4. Near-rural Porous Type Living Circle, located in urban-rural fringe areas, with fragmented structures and insufficient facilities; 5. Hollow-core Living Circle, with scarce internal facilities and high travel dependency; and 6. Fan-shaped Radiation Living

Circle, with a wide variety of facilities but isolated locations and insufficient transportation connectivity. Overall, living areas with the highest proportion of green travel often exhibit a complex spatial combination of "close accessibility, moderate density, diverse functions, and good road conditions," with all 16 types of facilities exceeding the city average. High green travel is generally located in core areas and major development corridors, while low green travel is concentrated in peripheral areas and new development areas. These differences are reflected not only in the number and distribution of facilities but also in whether key facilities are located within green travel-promoting zones. For example, the mean SHAP values of primary school accessibility in the three low-level living circles were -0.006, -0.002, and -0.004, respectively, which were not in the green travel promotion range.

The core finding of this chapter is that it offers a target space-inside behavior methodology for living circle green-travel-oriented renewal, including the green 15-minute cycling living circle planning threshold and green 15-minute cycling living circle samples. This chapter also reveals the core position of accessibility and density, and provides a reference for the setting of independent variables for the subsequent two single-type facility studies in Chapters 5 and 6.

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

The previous chapter analyzed all-type facilities green travel, and this chapter will analyze the green travel from the perspective of single-type facility, looking at the correlation between green travel mode choice and facility layout of single-type facilities, revealing the mechanisms by which the street environment influences walking and cycling. The paper uses OD flow clusters of 8 types of “residential quarter→facilities (e.g., supermarket)” (including only OD flow clusters within 15-minute cycling living circles) as samples. The paper integrates multi-source data from mobile phone travel, remote sensing, and road networks. Using the sample's green travel proportion as the dependent variable and 25 facility layout items (e.g., average street length) as independent variables, the paper uses Random Forest regression and PDP analysis to identify key drivers of walking and cycling choices, quantify the facility layout optimal range for green travel. Based on the key variables and threshold conversion values of the eight facility-influencing mechanisms, this chapter categorizes four types of streets, providing actionable thresholds for optimizing slow travel (Figure 5.1, Figure 5.2).

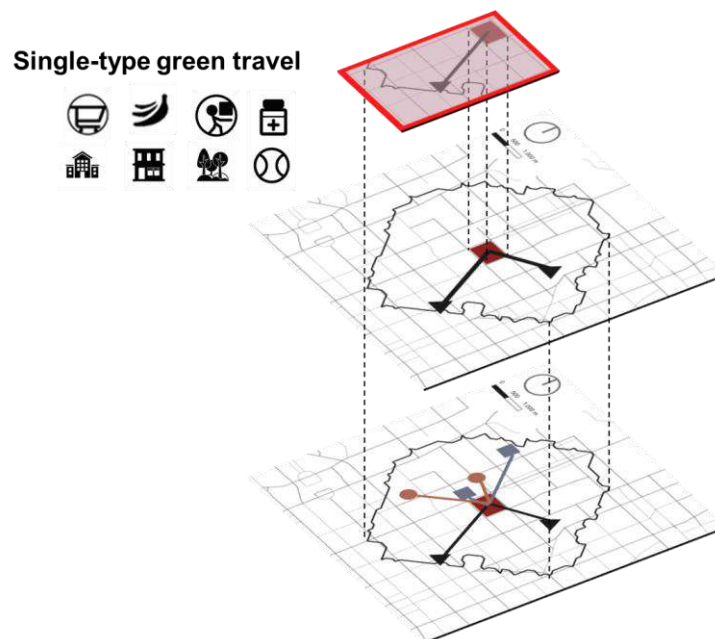


Figure 5.1 Travel behavior space of this chapter

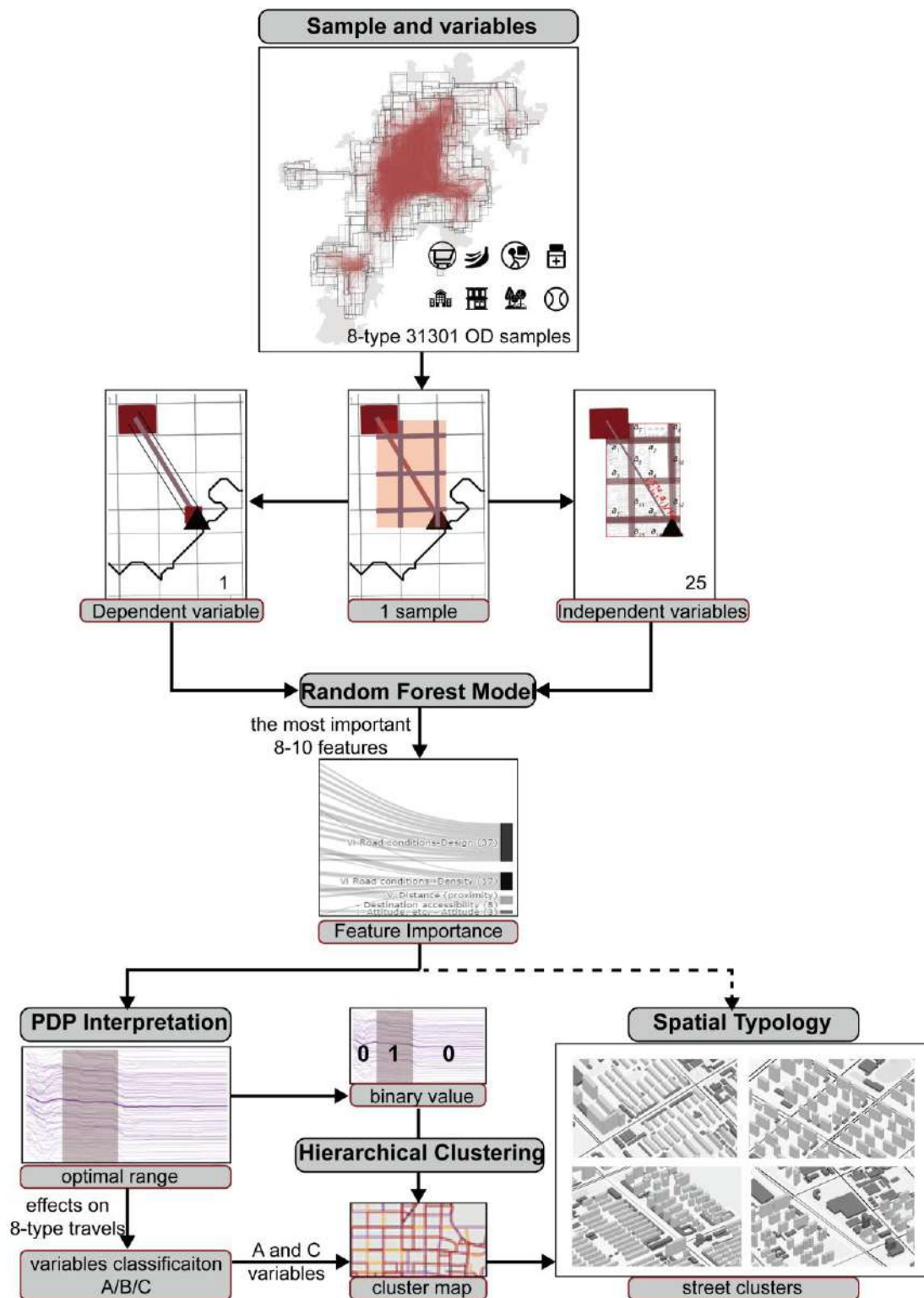


Figure 5.2 Framework of this chapter

In existing research on the correlation of space and green travel, the influencing factors of green travel behavior are often examined in a fragmented manner—typically focusing either on distance or on facility layout characteristics in isolation. For example, during unit selection, many studies rely on street segments or point-based locations to analyze how the built environment at these specific sites influences the frequency of green trips, while travel distance is omitted. Although some recent studies have adopted OD (origin – destination) units to investigate how distance and en-route environmental features affect travel behavior, such analyses often concern individual-level trips or are aggregated at a scale of local spatial grid, resulting in small samples or coarse spatial resolution. By contrast, this study of dissertation adopts residential quarters or facility parcels as the spatial aggregation units, constructs OD flow clusters from residences to facilities, and analyzes how OD distance and en-route spatial characteristics shape residents' choice of green travel modes. This approach enables both fine-grained analysis and large-sample evaluation, overcoming the limitations of earlier research.

5.1 Data, samples and variables

5.1.1 Data: multi-source data

The study utilizes multi-source data including mobile travel data, building data, road network data, water body data, DEM data, remote sensing imagery, and survey data. Detailed explanations of mobile travel data can be found in section 3.4.3.2, while the other data sources are introduced in 3.4.3.1.



Figure 5.3 Road and land use data from the third national survey of towns and villages

Figure 5.4 Water body data

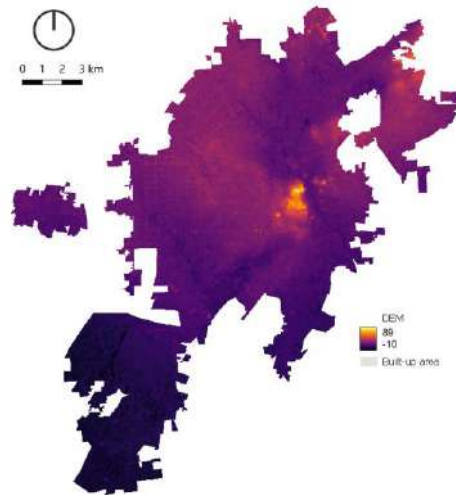
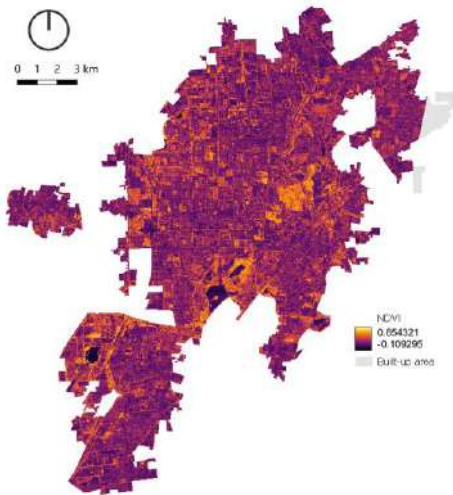


Figure 5.5 Remote sensing imagery data

Figure 5.6 DEM elevation data

5.1.2 Samples: 31301 eight-type OD flow clusters

This study selects 8 types of facilities—malls, hospitals, middle schools, cultural activity centers, park attractions, primary schools, vegetable markets, and community commercial outlets. The 31301 OD flow clusters from residential quarters to these facilities are used as the research sample. These 8 types of facilities cover various travel purposes, with a large number of samples, and have a significant impact on green travel.

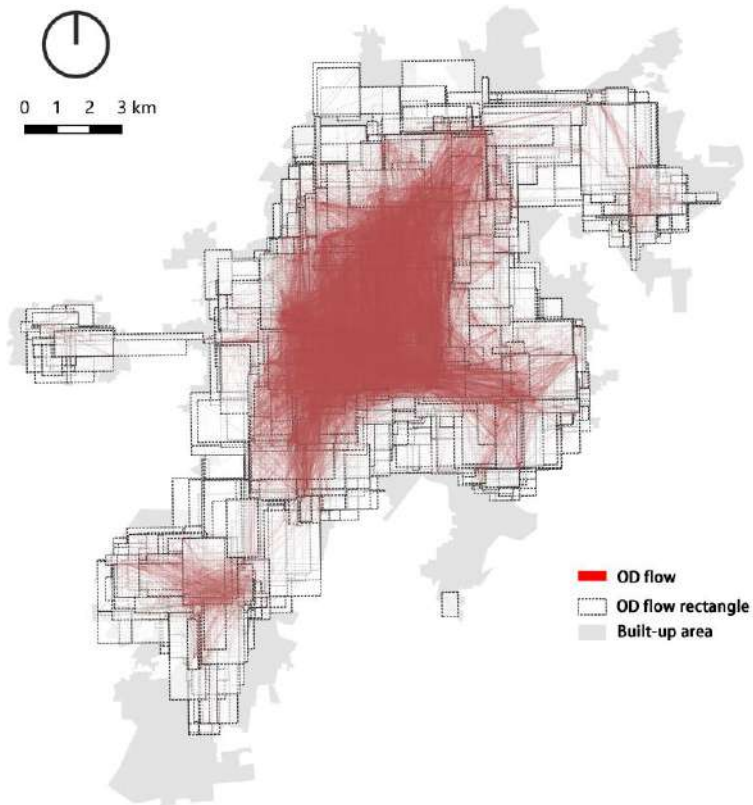


Figure 5.7 31301 OD flows samples and their rectangles

5.1.3 Dependent variable: green travel proportion of ODs

The dependent variable is the green travel proportion (i.e., the ratio of walking and cycling in all modes that walking, cycling, bus and car) from residential quarters to these facilities. Each of 31301 OD flow cluster of 8 facility types corresponds to a specific green travel proportion, the value range is 0-1.

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

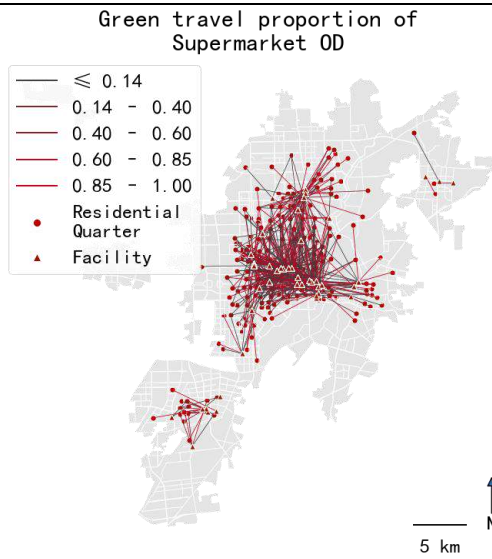


Figure 5.8 Green travel proportion of
Supermarket OD

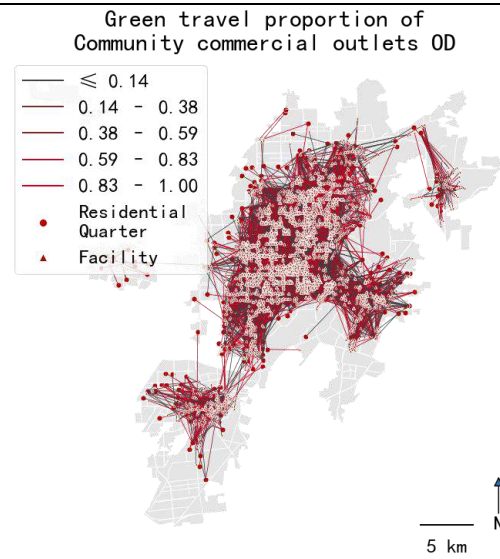


Figure 5.9 Green travel proportion of
Community commercial outlets OD

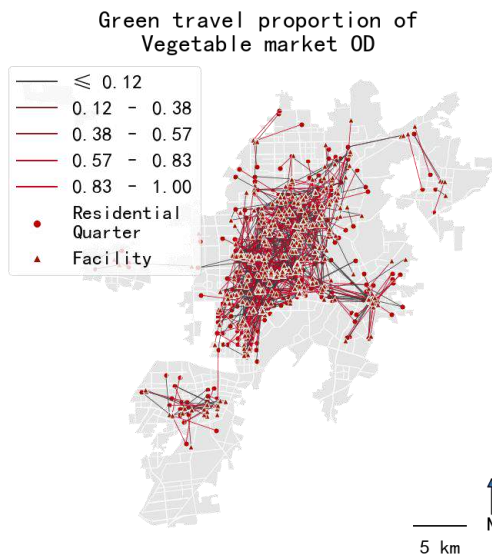


Figure 5.10 Green travel proportion of
Vegetable market OD

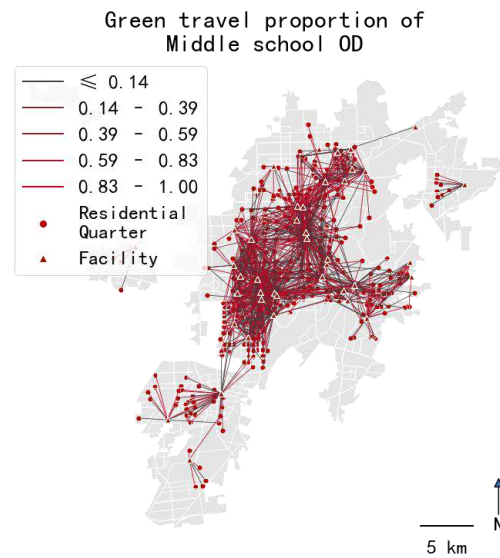


Figure 5.11 Green travel proportion of
Middle school OD

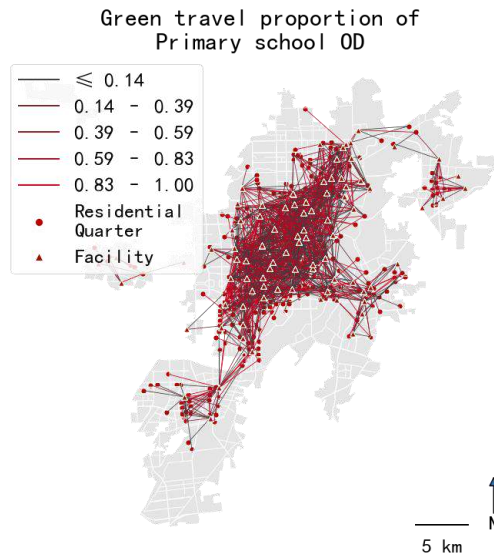


Figure 5.12 Green travel proportion of Primary school OD

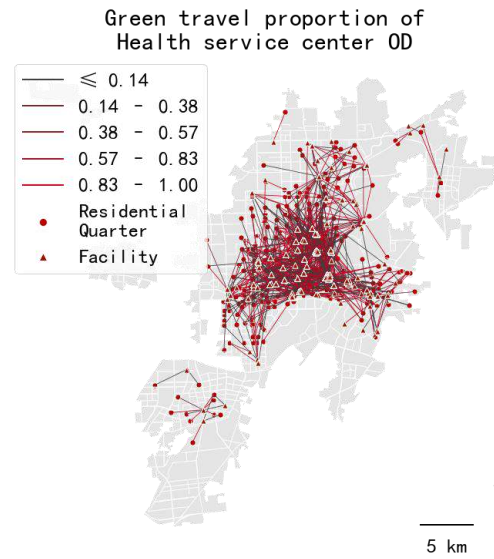


Figure 5.13 Green travel proportion of Health service center OD

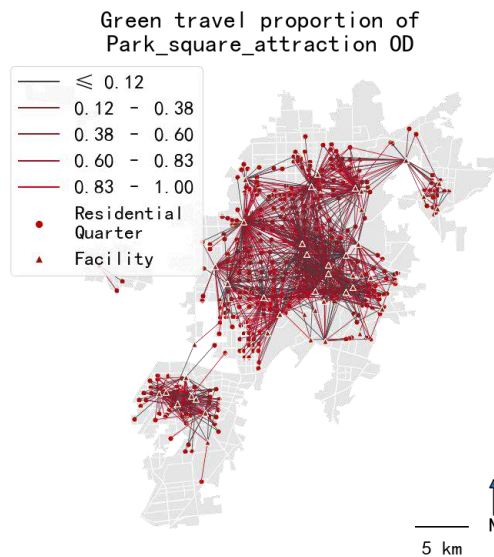


Figure 5.14 Green travel proportion of Park_square_attraction OD

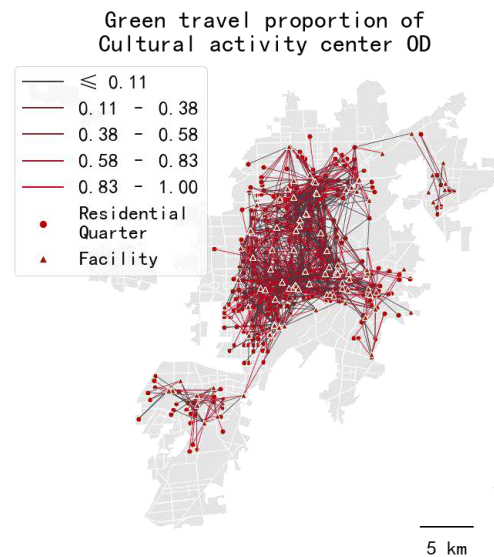


Figure 5.15 Green travel proportion of Cultural activity center OD

5.1.4 Independent variables: 25 facility layout indicators of ODs

Based on classical theories, literature reviews, field surveys, and authoritative walking evaluation frameworks, 25 independent variables for the OD flow clusters are

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE
AND FACILITY LAYOUT

constructed, covering social characteristics, spatial accessibility, and street environmental attributes. These variables are categorized into three dimensions: attitude, distance, and road condition (Table 5.1).

Table 5.1 25 OD flow cluster variables and corresponding dimensions

Interaction Dimension	Secondary Dimension	Indicator	Variable name	Unit
Attitude	Attitude	Green Travel Attitude of Residential quarter	greprefer0	None
	Tool	Car Ownership Rate of Residential quarter	cartool	None
	Tool	Bicycle Ownership Rate at Residential quarter	biketool	None
Accessibility	Destination accessibility	OD Flow Cluster Distance	ODdistan	Meters
Road Condition	Design	Average Street Length	length_mea	Meters
		Average Street Width	width_mea	Meters
		Average Road Class	rdclmea	Class
		Average Street Building Height, Mean	heimeamea	Meters
		Average Street Height-to-Width Ratio	heitwidmea	None
		Average Street Wall Continuity	contin_u_me	None
		Average Bike Lane Coverage	bimrlen1	None
		Average Greening Rate	ndvi_mea	None
		Average Water Body Coverage	water_mea1	None
		Average Elevation Range	dem_range1	Meters
		Average Slope	slope_mea1	Degrees
		Average Integration Value	INTmea	None
	Density	Average Street Transportation Facility Density	Dbus_stop, Dparking	Units per km ²
		Average Street Other Facility Category Density	Dxxx (Shopping DSHOP, Education DEDU, Health DHEALTH, Leisure DLEISURE)	Units per km ²
		Average Street 14-Category Facility Density	DALL14	Units per km ²
		Average Floor Area Ratio	Dbuilding	None

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AND FACILITY LAYOUT

	Average Residential Floor Area Ratio	Drebd	None
	Average Non-residential Floor Area Ratio	Dnorebd	None
Diversity	Average Street Building Story Height Diversity	heibunme	Meters
	Average Street Functional Mix	Fnmixmea	None
	Average Street Task Support Mix	Fnmix4mea	None

Before introducing the independent variables, let's first introduce the statistical space of the layout characteristics of OD flow cluster facilities (Figure 5.16). The statistical space for the layout of each OD flow cluster sample facility is the average spatial feature of the buffer zones on both sides of the rectangular street enclosed by the OD flow cluster (the street refers to the main road in the map). The reasons are as follows. Given that OD flow clusters are line segments without boundaries, it is not possible to statistically analyze spatial features through traditional spatial boundaries. Therefore, we need to analyze the possible travel paths of OD flow clusters and the spatial characteristics of the streets where they are located as spatial features of OD flow clusters. These spatial features affect the walking and cycling choices of OD flow cluster travel paths and the proportion of green travel in OD flow clusters. According to literature, there is no regularity in the selection of travel routes for determined starting and ending points, such as the shortest path, the path with the least number of turns, or other paths. Therefore, it is meaningless and foolish to assign higher weights to streets along any path. We directly treat all streets equally. In addition, we conducted statistical analysis on the street features within the rectangular range (with parallel or vertical boundaries) surrounding the starting and ending points of the OD flow cluster. The reason is that the roads or lanes in Tangshan's road network are mostly parallel or vertical, and the travel paths of the OD flow cluster are mostly within this rectangle. The street refers to the buffer zone on both sides of the vector street line within a range of 50 meters or 500 meters. Taking an OD flow cluster in a living circle as an example, the statistical process of its facility layout is shown in the following figure. When calculating specifically, first use each street as a statistical unit to calculate the length, width, and aspect ratio of the street (or the buffer zone on both sides of the street within a range of 50 meters or 500 meters). Secondly, use the OD flow cluster rectangle as the range to calculate the average of these street attributes within the rectangle, which is equivalent to calculating the average spatial characteristics of the buffer zones on both sides of the rectangular street surrounded by OD flow clusters.

The specific formula is as follows:

$$a_{mean} = \frac{\sum_{i=1}^n a_i}{n} \quad (5-1)$$

Among them, a_{mean} is the mean of a certain feature of all streets within the OD flow cluster sample rectangle, a_i is the target value of that feature of the OD flow cluster sample, a_i is the attribute value of each street within the OD flow cluster rectangle, and n is the number of streets in the OD flow cluster rectangle. For example, there are 14 streets within the rectangle in the figure, and the average street aspect ratio of these 14 streets is the OD flow cluster sample street aspect ratio. The reason why the street mean can be used as the mean of a certain feature of all streets in the OD flow cluster sample rectangle is that, based on the similarity law of geographical neighboring things (streets) and the current situation of Tangshan streets, the length of each street in the same rectangle is basically the same, and there is no need to use street length as a weight for weighted mean calculation. In the subsequent introduction of road condition indicators, only the statistical formula for each street condition (a_i) will be displayed, and the statistical formula for the average road condition of all streets within the OD flow cluster rectangle (a_{mean}) will no longer be displayed.

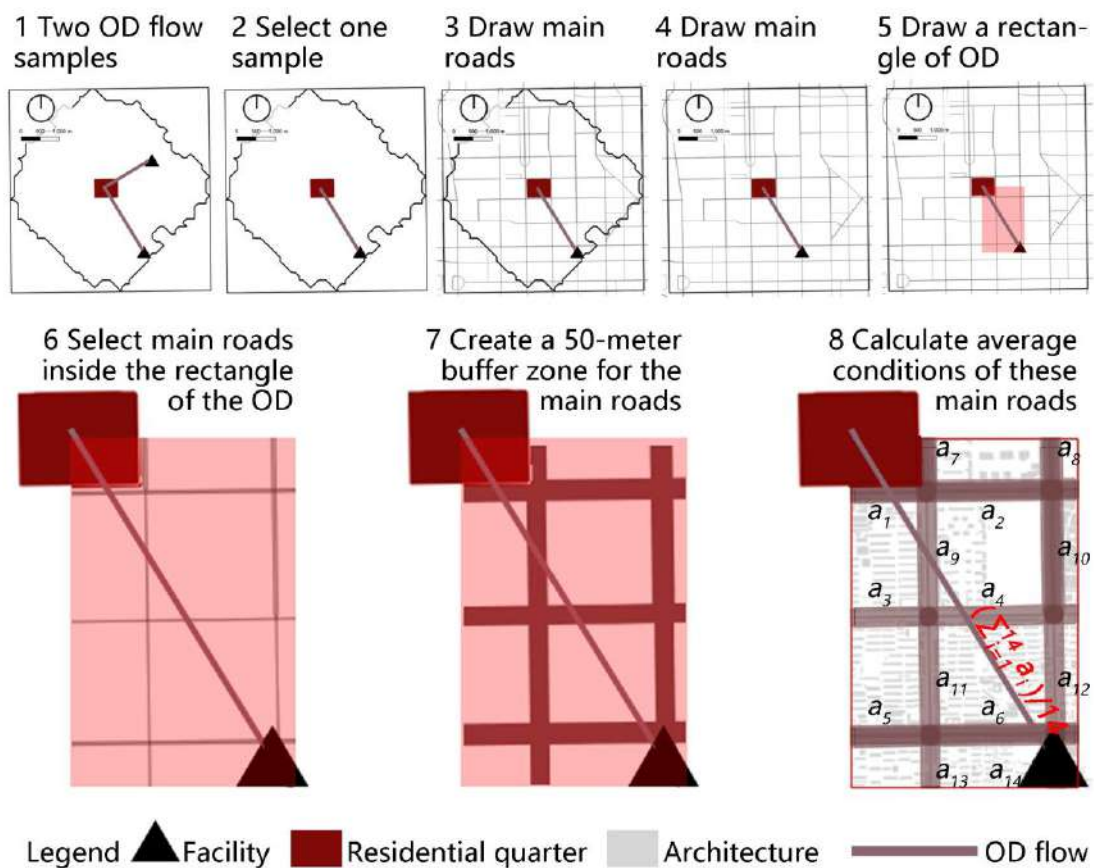


Figure 5.16 Schematic diagram of spatial characteristics statistics of OD flow clusters

Road Conditions - Design

The average street length (length_mea) refers to the average street length (in meters) of all streets within the OD flow cluster rectangle. This street refers to the main road of the traffic skeleton, corresponding to the main roads (primary and trunk), secondary roads (secondary), and tertiary roads in the OpenStreetMap data, as well as the urban road land in China's third land survey data, excluding roads within the plot. The length of a street reflects the scale of the block and directly determines the density, spacing, service radius, and travel distance of facilities. Shorter street lengths are associated with high levels of walkability and cycling. Figures show Tangshan streets length and the average value of OD flow (take Health service center facilities as examples) (Figure 5.17, Figure 5.18), other figures are shown in the same pattern: the street value and the average value of OD flow. The thesis shows some variables of all 25 variables, such as street length, width, grade, street building height, street aspect ratio, continuity of street walls, integration degree, residential building plot ratio. The introduction of each independent variable is

omitted, and a unified summary of all independent variables is given later.

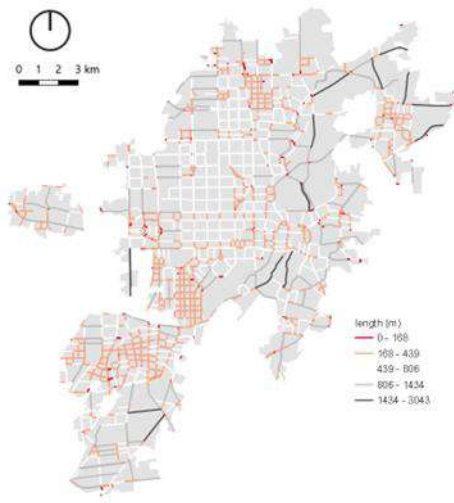


Figure 5.17 Street length

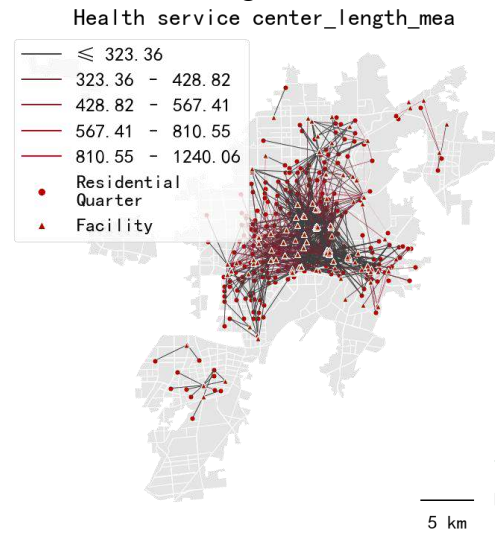


Figure 5.18 Average length of streets within the OD flow rectangle

The average width of streets (*width_mea*) refers to the average width (in meters) of all streets within the OD flow cluster rectangle. The width of a street reflects the width between the red lines of a road, which is the total width of various land uses in the cross-section of the road, including motor vehicle lanes, non motor vehicle lanes, sidewalks, green belts, etc. The comprehensive OSM road (*TS_roads_fenge_ID*) grade reference width for street width, government vector land use data (road land in the current land use category within the built-up area of the third national land survey), and QGIS real-time map measurement and assignment.

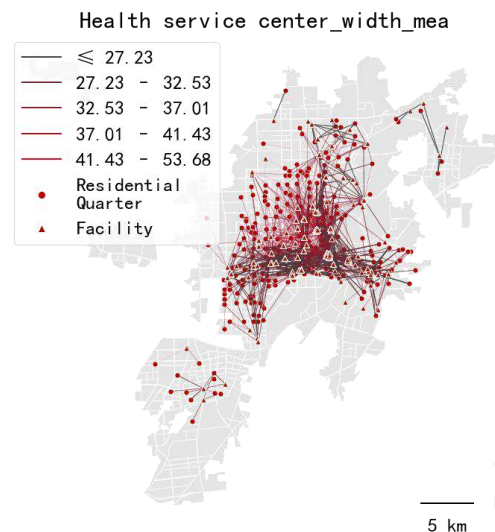
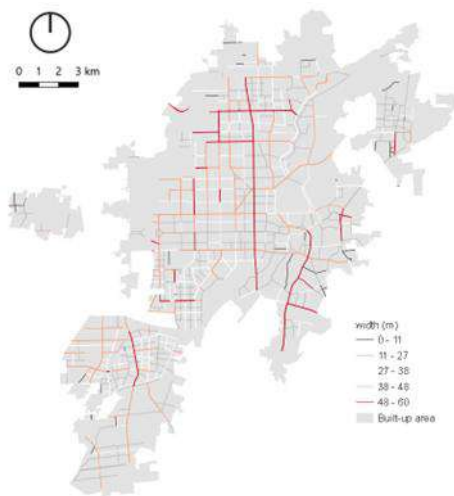


Figure 5.19 Street width

Figure 5.20 Average width of streets within
the OD flow rectangle

Road grade mean (rdclmea) refers to the average grade (without units) of all streets within the OD flow cluster rectangle. The road class reflects the importance of the street to the road system, with higher grades being more important. Based on the OSM road network, this article assigns the primary (and trunk), secondary, and tertiary fields of the fclass field to 1, 2, and 3, respectively. Trunk refers to the most important road in a country's highway network, excluding highways; Primary refers to the second most important road in a country's highway network, typically connecting larger city towns; Secondary refers to the third most important road in a country's highway network, typically connecting towns; Tertiary refers to the fourth most important road in a country's highway network, typically connecting small towns and villages. The road grade affects the traffic flow, air pollution, and travel safety of motor vehicles, which in turn affects walkability and cyclical^[155].

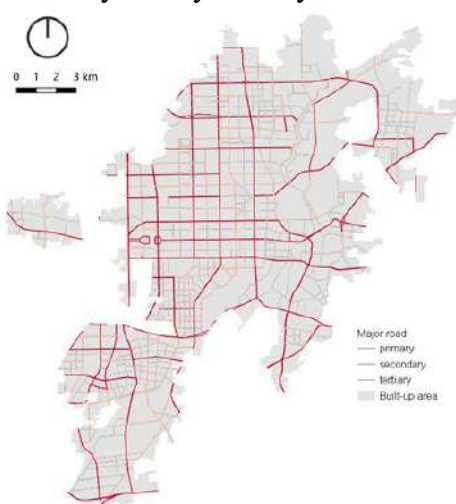


Figure 5.21 Street grade

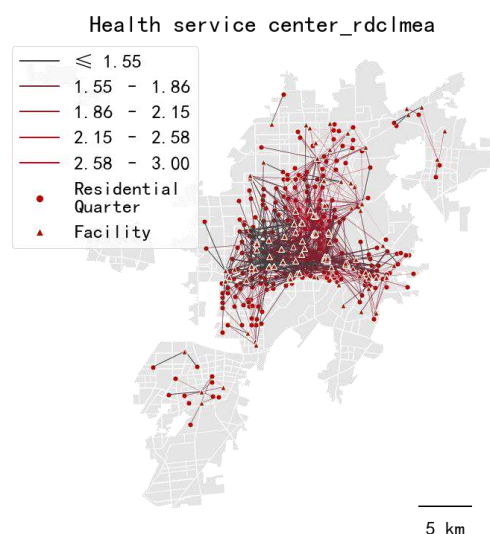


Figure 5.22 Average grade of streets within
the OD flow rectangle

The average height of street buildings (heimeamea) refers to the average height (in meters) of all street buildings within the OD flow cluster rectangle. The average height of street buildings (heimea) refers to the average height (in meters) of buildings within a 50 meter buffer zone on a street.

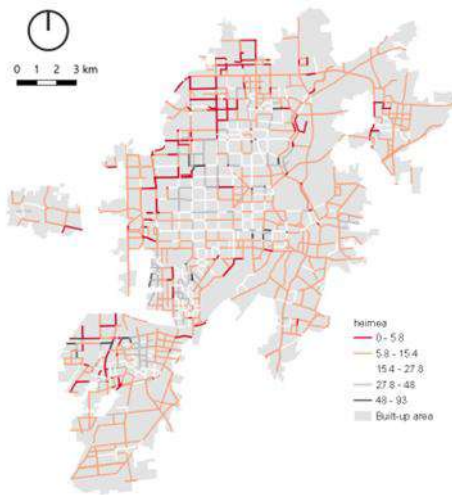


Figure 5.23 Street building height

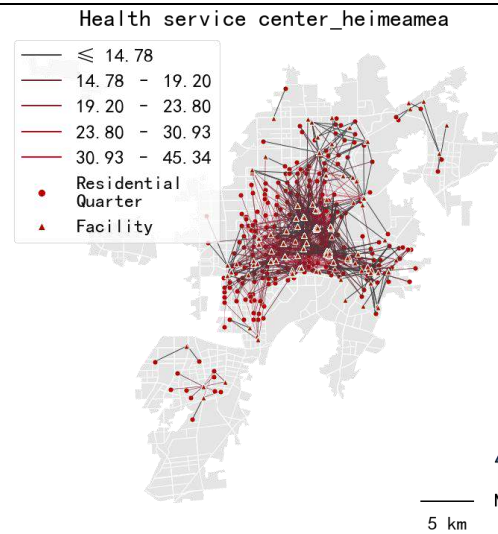


Figure 5.24 Average building height of streets within the OD flow rectangle

The average street aspect ratio (heitwidmea) refers to the average street aspect ratio (without units) of all streets within the OD flow cluster rectangle. For each street, the street height to width ratio (heitwid) refers to the ratio of the average building height of a 50m buffer zone divided by the street width (without units)^[155].

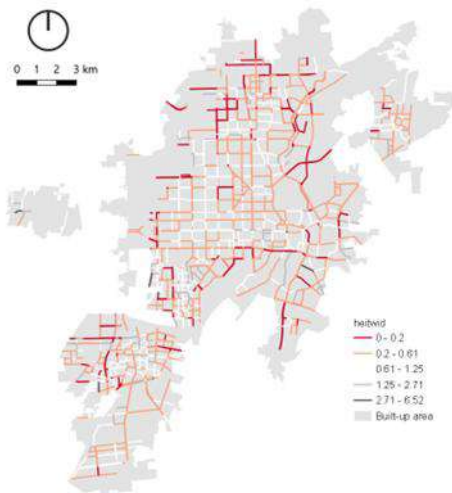


Figure 5.25 Street aspect ratio

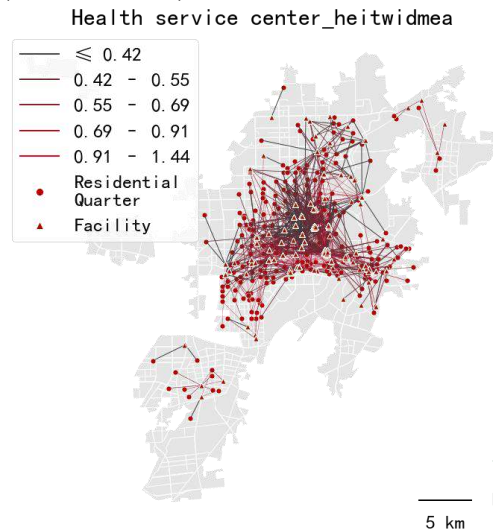


Figure 5.26 Average aspect ratio of streets within the OD flow rectangle

The average continuity of street walls (continu_me) refers to the average street continuity (without units) of all streets within the OD flow cluster rectangle. For each street, the continuity of the street wall refers to the degree of continuity of the buildings

along the street. In this study, for the nearest buildings on each street, the total length of the buildings whose long side forms an angle of less than 30 degrees with the street road red line is divided by the total length of the road as the street continuity.

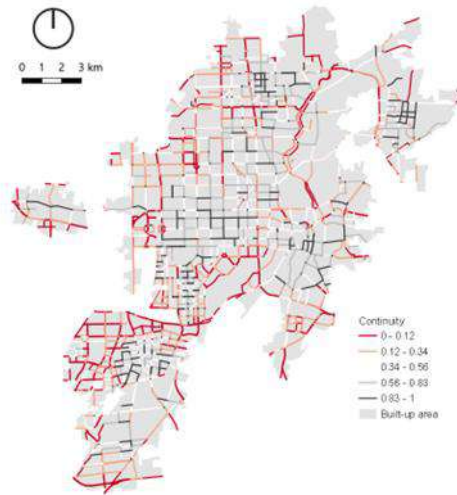


Figure 5.27 Street wall continuity

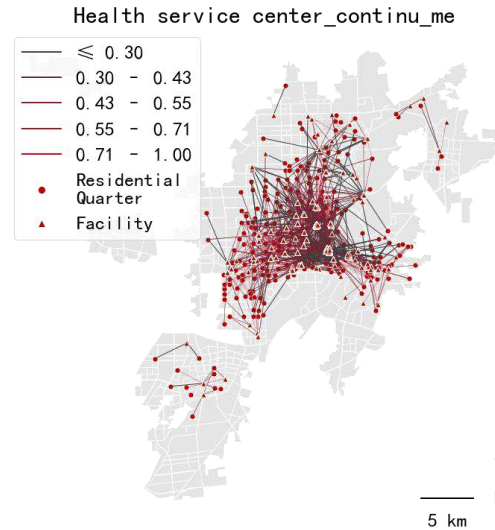


Figure 5.28 Average wall continuity of streets within the OD flow rectangle

Bimrlen1 refers to the average (without units) of the degree of bike lanes set up on all streets within the OD flow cluster rectangle. For each street, bike lanes refer to the degree of greenways and dedicated bike lanes within the 50 meter buffer zone of the street, assigned values based on whether they are set up and the degree of continuity (bike lane length divided by street length), with a range of 0-1.

The mean green coverage rate (ndvi_meal) refers to the average ndvi (without units) of all streets within the OD flow cluster rectangle. For each street, the NDVI value refers to the average NDVI of the grid within a 50 meter buffer zone (with a remote sensing image grid accuracy of 3m).

The average water area (water_meal) refers to the average water area of all streets within the OD flow cluster rectangle (without units). For each street, the water area refers to the current status of rivers, lakes, and other water bodies within a 50 meter buffer zone. It is assigned a value based on whether they exist. If they exist, it is 1, and if not, it is 0. Good greenery and water bodies are related to high walkability and cyclicity.

The average elevation range (dem_rangel) refers to the mean elevation range (in meters) of all streets within the OD flow cluster rectangle. For each street, elevation refers to the absolute height of a point on the surface relative to sea level, and elevation range

refers to the elevation range within a 500 meter buffer zone of the street (the difference between the maximum and minimum values), used to quantify the severity of terrain undulations. The elevation data comes from the USGS official website, with a grid accuracy of 12 meters. The larger the elevation difference, the more significant the slope changes and undulations along the road, which may increase the difficulty of travel; Flat areas with smaller undulations help reduce traffic resistance and improve the comfort and accessibility of green travel.

The average slope mean (slope_meal) refers to the average slope mean (degrees) of all streets within the OD flow cluster rectangle. For each street, the average slope refers to the average slope within the 500 meter buffer zone of the street, calculated based on QGIS "zone statistics". Slope reflects the degree of inclination of the earth's surface, and its value is equal to the arctangent of the ratio of the vertical height difference to the horizontal distance within a certain buffer zone on both sides of the road. The average slope of larger street buffer zones mean that pedestrians need to overcome higher energy consumption and physical burden when walking or cycling, which may suppress their willingness to travel green.

The mean integration degree (INTmea) refers to the average integration degree (without units) of all streets within the OD flow cluster rectangle. Integration degree is a classic indicator in spatial syntax. For each street, Integration degree (INT) means the average depth of this street compared to all other streets in the system; Pedestrians need fewer turns to reach streets with high integration, while streets with lower integration (usually like dead ends) require more directional changes to reach their destination. To a certain extent, the degree of integration characterizes the distance between a street and the city center, reflecting the macro location^[157]. This study chooses Normalized Angular Integration (NAIN) and calculates it according to the following formula:

$$NAIN = \frac{(NC + 2)^{1.2}}{ATD} \quad (5-2)$$

The indicator is calculated by the spatial syntax software Depthmap, with a radius set to 800 meters (INTr800), where NC (node count) represents the number of street nodes directly connected to the target street segment within a radiation range of 800 meters, and ATD (angular total depth) is the sum of the required angle turning depths from the target street segment along the street network to all street segments within the same range. NAIN quantifies the accessibility and accessibility of streets in the overall network by

normalizing the depth of angles - the larger the value, the easier it is to reach the street from other parts of the network, making it more central and attractive in walking and cycling networks. The reason for choosing 800 meters as the calculation radius is twofold: firstly, the differentiation between streets within the 800-meter range is relatively high, and secondly, it is in line with the size of the living circle.

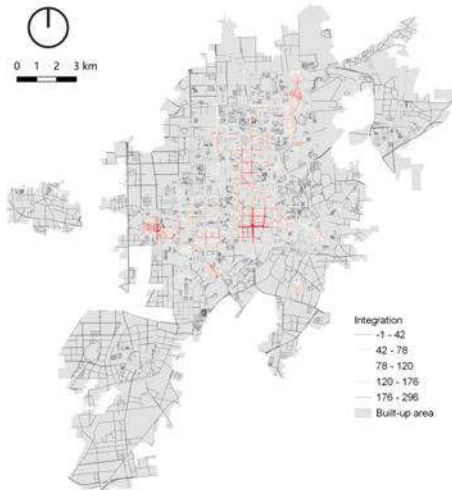


Figure 5.29 Street Integration degree

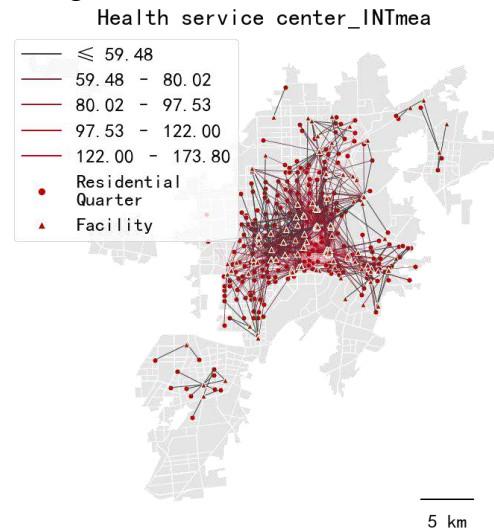


Figure 5.30 Average Integration degree of streets within the OD flow rectangle

Road Conditions Diversity

The average diversity of building heights in streets (heiunme) refers to the average diversity (class) of building heights in all streets within the OD flow cluster rectangle. For each street, the diversity of building heights refers to the number of building height categories within the 50-meter buffer zone of the street. For example, if all are 9 meters, the number of categories is 1, and if they are 9 meters or 27 meters, the number of categories is 2. The change in building height brings about a staggered scene and dynamic changes in light and shadow. Different building heights can enrich the spatial experience, and the ratio of building height to street width is constantly changing. Diversity is also beneficial for creating rich urban forms, active facades, and diverse and easily understandable public spaces. The above satisfies people's aesthetic and fun experiences to promote walking and cycling.

Fnmixmea refers to the mean (without units) of the street function mix of all streets within the OD flow cluster rectangle. For each street, the street functional mix (Func_mix) measures the functional diversity within a 50-meter buffer zone of the street, using the

information entropy calculation method as a reference:

$$\text{Func\_mix} = - \sum_{i=1}^n (p_i \times \ln p_i) \quad (5-3)$$

Among them, p_i represents the proportion of facilities of different i types along each street to the total facilities, n represents the number of categories of POIs for that street, and normalizes all types of POIs. The type in the formula refers to the classification of 14 i types of facilities, and the degree of mixing refers to the degree of mixing of these 14 types of facilities.

The average mixing degree of street support tasks (Fnmix4mea) refers to the average mixing degree (without units) of all streets within the OD flow cluster rectangle that supports residents to complete tasks. For each street, the street support task mixture (Func_mix_4) measures the mixture of facilities within a 50-meter buffer zone that supports residents in completing tasks. Residents travel to complete "tasks". Taking education as an example, if middle school is the goal, it is impossible to go to primary school and kindergarten. On the contrary, residents may also aim for a "supermarket" for shopping. Therefore, this indicator reflects the conditions under which the street supports people to complete tasks. Calculate the functional mix of the same street, but replace the 14 subcategories with four major categories (shopping, learning, caring, and enjoying).

Road Conditions Density

The average density of street traffic facilities (Dbus_stop, Dparking) refers to the average density of traffic facilities (units/square kilometer) of all streets within the OD flow cluster rectangle. For each street, the density of street traffic facilities refers to the density of two types of traffic facilities (bus stop POI or parking lot POI) within the 50 meter buffer zone of the street. The calculation method is to divide the number of bus stop POI or parking lot POI facilities in the 50-meter buffer zone of the street by the area of the 50 meter buffer zone.

The average classification density of other facilities in the street (four categories: shopping, education, health, and leisure) refers to the average classification density of other facilities in all streets within the OD flow cluster rectangle (units/square kilometer). For each street, the classification density of other facilities in the street refers to the number of facilities classified by category (four major categories) within the 50 meter buffer zone of the street. The specific calculation formula for the indicators is as follows:

$$D_{xxx} = \frac{\sum_{i=1}^n a_i}{A_{50bf}} \quad (5-4)$$

Among them, A_{50bf} is the area of the 50-meter buffer zone on the street, a_i is the number of facilities of a certain type (14 subcategories) within the buffer zone, and n is the number of facility types included in the large category. For example, the "education" category includes three subcategories: "junior high school", "primary school", and "kindergarten". The four major categories include subcategories: shopping includes supermarkets, vegetables, community commercial outlets, catering, and express; Education includes junior high schools, primary schools, and kindergarten; Health includes a health service center, gym fitness center, and pharmacy; Leisure activities include community service center, cultural activity center, park_square_attraction.

The average density of 14 types of facilities in a street (DALL14) refers to the average density of 14 types of facilities in all streets within the OD flow cluster rectangle (units/square kilometer). For each street, the density of 14 types of facilities refers to the density of 14 types of facilities within the 50-meter buffer zone of the street (facilities outside of the two types of transportation facilities, as indicated by the subcategory in the same indicator). The calculation method is to divide the number of 14 types of facilities in the 50-meter buffer zone of the street by the area of the 50-meter buffer zone.

The average building plot ratio (Dbuilding) refers to the average building plot ratio (without units) of all streets within the OD flow cluster rectangle. For each street, the building plot ratio reflects the intensity of nearby construction and refers to the building plot ratio within a 500m buffer zone of the street. The calculation method is to divide the total area of all buildings within the buffer zone by the area of the 500m buffer zone of the street. The mean residential building plot ratio (Drebd) and non-residential building density (Dnorebd) have similar meanings to the mean building plot ratio (Dbuilding), referring to the mean of all residential building plot ratios (D_re_bd) or all non-residential building plot ratios (D_no_re_bd) within the OD flow cluster, respectively. Non-residential buildings refer to various types of buildings, including office, leisure, shopping, education, etc., excluding residential buildings. The building outline is derived from disaster data and filtered based on the boundaries of residential quarters in Chapter 4. The calculation of indicators is based on building data and 500m buffer zone data on streets. High intensity of residential construction is usually associated with a higher population

and high demand for facilities, while high intensity of non-residential construction usually means mature and functionally complex construction, corresponding to a higher density of facility layout and higher walkability and cyclical. For each street, the calculation method for residential or non-residential building plot ratio (D_{re_bd}) or non-residential building plot ratio ($D_{no\_re\_bd}$) is the total area of residential or non-residential buildings within the buffer zone divided by the 500m buffer zone area of the street, where the total area of residential or non-residential buildings is the product of the number of floors and the floor area of the building. The specific calculation formula for the indicators is as follows:

$$D_{re\_bd} = \frac{\sum_{i=1}^n A_{r\_i}}{A_{500bf}} \quad (5-5)$$

$$D_{no\_re\_bd} = \frac{\sum_{i=1}^n A_{nor\_i}}{A_{500bf}} \quad (5-6)$$

Among them, A_{500bf} is the area of the 500m buffer zone on the street, A_{r_i} and A_{nor_i} is the total area of each residential or non-residential building within the buffer zone, and n is the number of residential or non-residential buildings in each buffer zone. The above areas are all projected areas. Figures show Tangshan streets length and the average value of OD flow, from city to suburb, the length values first become shorter and then longer.

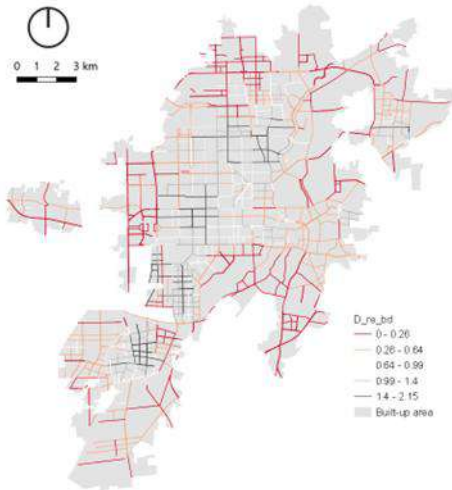


Figure 5.31 Street residential building plot ratios

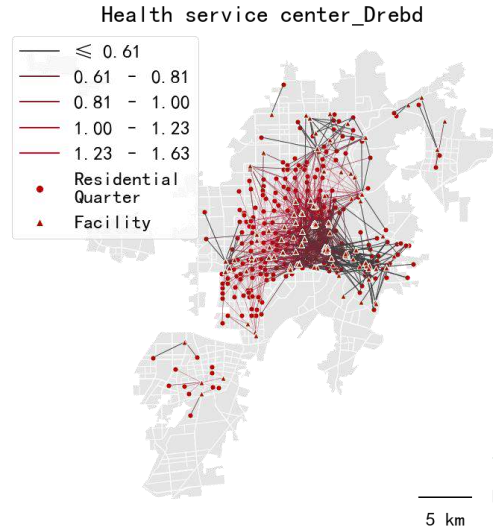


Figure 5.32 Average residential building plot ratios of streets within the OD flow rectangle

Accessibility - Destination accessibility

This dimension includes an indicator, OD flow cluster distance, which refers to the Euclidean distance (in meters) of the line segment connecting the centroid of the starting residential quarter to the centroid of the endpoint facility (POI).

Attitude - Attitude

In this study, the attitude and other dimensions of the whole class research were used to measure the social characteristics of the residential quarters at the starting point of the OD flow cluster. Please refer to section 4.1.4 for the attitude calculation method.

Attitude - Tool

The tool dimension includes two indicators, car ownership rate and bicycle ownership rate, which respectively reflect the tool ownership situation in the starting residential quarter of the OD flow cluster. Please refer to section 4.1.4 for the calculation method of the tool.

$$cartool = \frac{private\ car}{All} \quad (5-7)$$

$$biketool = \frac{bike + electric\ bike}{All} \quad (5-8)$$

Among them, *private car* represents private cars, *bike + electric bike* represents private bicycles and electric bicycles, and *All* represents the total number of questionnaires in the residential quarter. The calculation is also based on the Tangshan satisfaction questionnaire, please refer to the *Attitude* indicators for questionnaire details. Based on the number of parking lots in residential quarters, the author validated *cartool* and proved that it can better reflect the situation of car ownership. Regarding these three indicators, in statistics, if the number of questionnaire samples (points) in a residential quarter is less than 10, it will be recorded as null.

In summary, based on the figures of variables of street length, width, grade, street building height, street aspect ratio, continuity of street walls, integration degree, residential building plot ratio (Figure 5.17 - Figure 5.32), street design tends to show distinct trends from the city center to the periphery. For example, streets in the city center are typically shorter and wider, with taller buildings, better wall continuity, and a higher degree of street integration. In contrast, in the periphery, streets are typically longer and narrower, with gradually decreasing building heights, resulting in less connectivity and integration. These changes are closely related to the spatial layout of urban functions. The

"compact," high-density development and multifunctional layout of the city center make streets more connected and accessible, while the periphery, often characterized by sprawl and rural characteristics, has more "open" streets, lacking this functional concentration and diversity.

5.2 Methods

The study uses a random forest regression model combined with partial dependence analysis to characterize the sensitivity threshold of environmental variables in the surrounding streets of different facility types to green travel (walking and cycling) behavior.

5.2.1 Random forest training and variable importance identification

This article adopts the Random Forest Regression (RFR) model. This model was developed using the widely used machine learning library Scikit Learn version 1.0.2^[143].

In the data preprocessing stage, the corresponding OD flow cluster travel records are first screened based on different facility types, and incomplete samples caused by the absence of dependent variables (green travel proportion) or key independent variables are eliminated; Secondly, multiple thresholds ($nmbtra \geq 3, 4, \dots, 10$) are set based on travel frequency ($nmbtra$) to eliminate low-frequency travel noise, and at least 5 samples are guaranteed for model training under each frequency threshold; Finally, all independent variables are uniformly subjected to mean imputation ($strategy='means'$) to handle the remaining missing values, in order to maintain data integrity and robustness of the analysis.

During the model construction phase, the study used RandomForestRegressor ($n\_estimators=100$, $random\_state=42$) as the base learner and divided the data into training and testing sets in an 80%/20% ratio ($train\_test\_split$ ($test\_size=0.2$, $random\_state=42$)). Subsequently, an "exhaustive" search (grid search) is performed, which involves applying Recursive Feature Elimination (RFE) to a predetermined number of feature preserves ($n\_features\_touselect \in \{8,9,10\}$) at each travel frequency threshold for subset selection. After fitting the candidate feature set on the training set, R^2 is calculated on the testing set. Ultimately, the study aims to select the optimal feature dimension combination that maximizes R^2 , in order to ensure that the model has both good predictive performance and the ability to extract the most explanatory key variables.

We pre-set $n\_features\_to\_use \in \{8,9,10\}$ in recursive feature elimination to control model complexity and reduce overfitting risk while covering the main driving factors. The experimental results indicate that the model performs best within this feature dimension range. Therefore, selecting a subset of 8-10 features can ensure explanatory power and facilitate subsequent analysis.

The results of eight regression models indicate that the model fit (R^2) of Supermarket at the optimal threshold of 8 and the number of features of 10 is 37.24%, with an RMSE of 0.1254; When the threshold is 7 and the feature count is 9, the R^2 of the hospital clinic is 39.47%, and the RMSE is 0.1469; The R^2 of middle school and cultural activity center under the optimal combination are 19.62% and 19.06%, respectively, with RMSE of 0.2343 and 0.2426, respectively; Park_SquareAttractions has a rate of 10.65% (RMSE of 0.1615), Primary School has a rate of 24.89% (RMSE of 0.2339), Vegetable Market has a rate of 21.04% (RMSE of 0.2693), and Community Commercial Outlets has a rate of 16.56% (RMSE of 0.2612). Although the overall R^2 is not high, due to the complex influence of multidimensional socio-economic factors on green travel behavior and the general difficulty in achieving high fit, as well as the consistency of the ranking, threshold, and academic conclusions of various independent variables in the model, the performance of the model in this study has reached a reasonable level in the research field, and the results have good theoretical interpretability and practical guidance significance.

5.2.2 PDP curve visualization and green travel threshold extraction

Random forests effectively capture nonlinear relationships and interaction effects between independent variables, but their "black box" nature makes it difficult to intuitively understand the decision-making process within the model. In order to analyze the specific impact and threshold of each variable in the random forest model on green travel behavior, the study further introduces Partial Dependence Plot (PDP) to visually reveal the average response of the model to changes in a single independent variable, and explore the relationship between facility type and green travel behavior.

Partial Dependency Graph (PDP) can illustrate the dependency relationship between the dependent variable and the independent variable in a machine learning model by displaying the average response of each possible value of the independent variable [85]. PDP can describe the nonlinear relationship between the rectangular characteristics of OD f

low clusters and the proportion of green travel in flow clusters, revealing the key thresholds that affect the degree of change in green travel caused by the main features. These thresholds can serve as reference values for green travel oriented urban design. It is mainly divided into two stages: drawing curves and extracting independent variable thresholds that promote green travel.

During the PDP curve drawing phase, for each feature screened from the optimal model of the random forest, use `plot_partial_dependence (... , kind='both', grid_resolution=50, line_kw={'color':'#xxxxxx'}, ice_lines_kw={'color':'#xxxxxx','alpha':0.2})` Simultaneously draw the global dependency curve and individual ICE lines.

In the threshold extraction stage, two strategies were constructed. (1) For the ODDistance, we define the distance corresponding to a green travel probability of 50% in the PDP curve as the "Green Travel Threshold Distance". This threshold not only characterizes the maximum effective support range of facilities for green travel, but also forms a dual threshold standard for green travel-oriented facility layout together with the minimum service radius under the entire travel model. (2) Except for travel distance, the green travel threshold of other independent variables is mainly determined by the "predicted mean method" - extracting the theoretical optimal design value based on the PDP predicted value mean - and the "maximum slope point method" - identifying the point with the highest slope of the PDP curve as the key control threshold. When the maximum slope point is too close to the edge, the predicted mean method is preferred, providing strategic basis for the theoretical analysis and practical configuration of green travel rules.

5.2.3 Street clustering by threshold-binary value and hierarchical method

After extracting the green travel thresholds of each variable, the study applied a hierarchical clustering method based on Jaccard distance and average linkage strategy to classify the types of main roads. Specifically, for each main road and independent variable, a new independent variable column is generated. If the original independent variable is within the green travel threshold, it is assigned a value of 1, otherwise it is assigned a value of 0, representing whether each variable falls within the green travel optimal range; Secondly, Jaccard dissimilarity coefficient is calculated for the 0/1 binary feature vectors of each road to measure the degree of matching between the two roads in the "promote/not promote" attribute; Subsequently, perform average chain clustering on the distance matrix and extract four clusters from the tree graph.

The adoption of this scheme is mainly based on the following points:

Cluster balance and interpretability: Compared with K-modes and K-means, hierarchical clustering generates more balanced cluster sizes under the same number of clusters, and the feature mean distribution of each cluster is more distinguishable. Whether it is the number of roads within the cluster or the activation degree of binary features, they can clearly reflect different street types;

Adaptability to non Euclidean binary data: Jaccard distance is naturally suitable for binary variables, highlighting the importance of matching "simultaneously 1" and avoiding false similarity under Euclidean measurement;

The flexibility of tree structure: Hierarchical clustering not only visually displays the aggregation process between different road types, but also facilitates dynamic adjustment of cluster numbers or merging or splitting of clusters according to research needs in the future.

Table 5.2 The setting and evaluation metrics of 8 Random Forest models, parameters for eight facility types

Eight facility types	Facility	OD travel threshold	Feature number	R2	RMSE
Supermarkets	Supermarket	8	10	0.3724	0.1254
Hospitals and clinics	Health service center	7	9	0.3947	0.1469
Middle schools	Middle school	6	8	0.1962	0.2343
Cultural activities	Cultural activity center	6	9	0.1906	0.2426
Parks, squares, and attractions	Park_square_attractions	12	8	0.1065	0.1615
Primary schools	Primary school	5	8	0.2489	0.2339
Vegetable markets	Vegetable market	5	10	0.2104	0.2693
Community commercial	Community commercial outlets	9	10	0.1656	0.2612

5.3 Regression results: importance, optimal ranges and classification of variables to green travels

5.3.1 Importance: accessibility, design, and density as core dimensions

From the frequency of occurrence of variables in various interaction dimensions, the mechanism of green travel behavior reflects the spatial environmental impact characteristics dominated by the "road condition design" dimension. The related variables in this dimension (such as terrain undulations dem_range1 6 times, street segment length length_mea 2 times, street wall continuity continuum-me 2 times, etc.) appear a total of 37 times, indicating a significant shaping effect of street microenvironment on travel intention. Next is the dimension of "road condition density", which appears a total of 17 times, covering non-residential building plot ratio Dnorebd 5 times, residential density Drebd 3 times, bus stop density Dbus_stop 4 times, etc., emphasizing the basic support of functional agglomeration and population carrying capacity for green travel. ODdistan, as the only variable in the "Accessibility" dimension, ranks first among all eight types of facilities, appearing 8 times in total, highlighting its dominant threshold role in green travel. At the same time, variables related to "attitude and tools" also play a moderating role in multiple facilities, with variables such as "motor vehicle ownership rate" and "green preference index" appearing 8 times, indicating that residents' subjective willingness and accessibility of transportation cannot be ignored in green travel choices.

Table 5.3 Variable importance results for eight facility types including supermarkets

Eight facility types		Most important	Coefficient 1	Second most important	Coefficient 2	Third most important	Coefficient 3	Fourth most important	Coefficient 4	Fifth most important	Coefficient 5	Sixth most important	Coefficient 6	Seventh most important	Coefficient 7	Eighth most important	Coefficient 8	Ninth most important	Coefficient 9	Tenth most important	Coefficient 10
Supermarkets	Supermarket	ODdistan	0.229922	Dparking	0.114805	dem_angle1	0.114196	length_meal	0.0859	INTmea	0.08354	bimrlen1	0.081505	grepr_efer0	0.079135	Drebd	0.071388	Dnor_ebd	0.070332	contin_u_me	0.069277
Hospitals	Health service center	ODdistan	0.608924	Fnmix4mea	0.064746	Dbus_stop	0.060293	Drebd	0.050554	dem_angle1	0.048007	cartool	0.046558	Fnmixmea	0.043845	heitwidmea	0.039359	biketool	0.037714	—	—
Junior high schools	Middle school	ODdistan	0.199102	cartool	0.131597	Dnored	0.122693	rdclmea	0.114531	DALL14	0.11005	heim_eamea	0.108998	Dbus_stop	0.108074	ndvi_meal	0.104955	—	—	—	—
Cultural activities	Cultural activity center	ODdistan	0.188087	DLEISUR_E	0.143853	dem_angle1	0.117364	DED_U	0.106347	width_meal	0.103246	ndvi_meal	0.093	Dnor_ebd	0.088709	grepr_efer0	0.083165	length_meal	0.076229	—	—
Parks, squares, and attractions	Park_square_attractions	ODdistan	0.204487	DHEALTH	0.121452	slope_meal	0.118911	dem_angle1	0.115749	Dbus_stop	0.114956	bimrlen1	0.114888	heim_eamea	0.110711	INTmea	0.098845	—	—	—	—
Primary schools	Primary school	ODdistan	0.302316	Dbus_stop	0.110985	Dnored	0.109067	heitwidmea	0.104852	Drebd	0.098144	width_meal	0.097904	INTmea	0.090865	DED_U	0.085867	—	—	—	—
Vegetable markets	Vegetable market	ODdistan	0.25785	dem_angle1	0.117563	ndvi_meal	0.09586	bimrlen1	0.089256	slope_meal	0.082648	Dnor_ebd	0.081132	rdclmea	0.079553	cartool	0.072072	width_meal	0.063272	heim_eamea	0.060795
Community commercial	Community commercial outlets	ODdistan	0.180183	INTmea	0.095808	dem_angle1	0.095407	cartool	0.093317	contin_u_me	0.093193	rdclmea	0.093114	Dparking	0.090541	bimrlen1	0.088765	grepr_efer0	0.085133	ndvi_meal	0.084539

Facility → Variable → Interaction Dimension Sankey Diagram

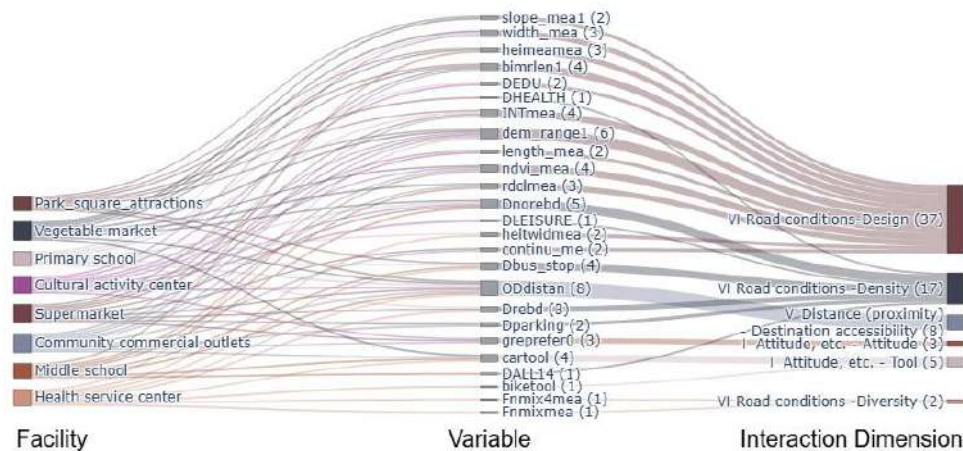


Figure 5.33 Sankey diagram of the importance of independent variables for eight types of facilities, including supermarkets, based on frequency

According to the sum of important coefficients of various interaction dimension variables in the green travel model, the mechanism of green travel behavior presents a dual driving feature of "distance accessibility" as the main factor and "road condition design" as the auxiliary factor. Among them, ODdistan, as the only included "accessibility" variable, is the first variable with the highest weight among all eight types of facilities, with a total importance coefficient of 2.17, indicating its position as the primary threshold for green travel decision-making.

Among other dimensions, the "road condition design" dimension ranks first with a total coefficient of 3.42, indicating that the spatial quality of the street microenvironment plays a key supporting role in green travel. Among them, representative variables such as terrain undulation dem_range1 (appearing in 6 types of facilities, with a total importance coefficient of 0.61), street segment length length_meal (0.16), street height heimeamea (0.28), street wall continuity continu_me (0.16), street aspect ratio (0.14), and bicycle lane setting bimrlen1 (0.37) showed stable positive effects in multiple facilities.

The total important coefficient of the "VI Density" dimension is 1.67, with non-residential building density Dnored (0.47) and residential density Drebd (0.22) as key variables, emphasizing the structural support of population and functional carrying capacity for green travel.

In the dimension of "Attitude and Tools (I)", the total importance coefficient of

"Tool" variables such as cartool and biketool is 0.38, and the importance coefficient of "Attitude" variable grefavorer0 is 0.25. This reflects that although subjective preferences and accessibility of transportation are secondary factors, they still play a moderating role in specific facility types, especially in community commerce, cultural activities, and junior high school facilities.

The overall coefficient of the "Road Condition Diversity" dimension is only 0.11, indicating that although functional diversity has a positive impact on some facilities (such as hospitals and cultural facilities), the overall impact is limited.

Facility → Variable (importance) → Interaction Dimension (importance) Sankey Diagram

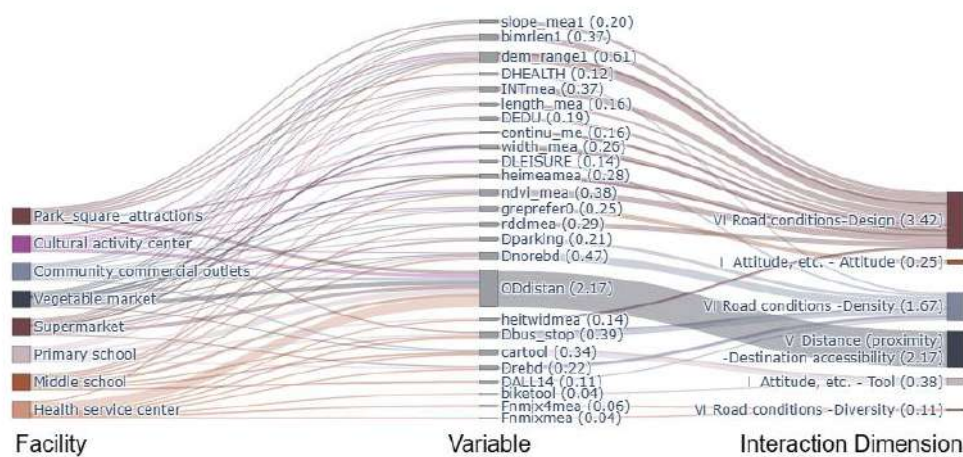


Figure 5.34 Sankey diagram of the importance of independent variables for eight types of facilities, including supermarkets, based on their importance

Based on the comprehensive frequency and importance coefficient, the green travel mechanism exhibits a multidimensional coupling feature of "accessibility dominance street design support density and subjective factor assistance". ODdistan, as the core variable of the "distance accessibility" dimension, has the highest weight among all facilities; The variable of "road condition design" dimension, although dispersed, has the highest frequency (such as dem_range1, length_meal, bimrlen1, etc.), indicating the key support of street microenvironment for travel choices. The "road condition density" dimension provides functionality and population base, while the "attitude and tools" dimension reflects the regulatory impact of transportation accessibility and green preferences on some facilities. The overall contribution of "road condition diversity" is relatively small, mainly having a positive effect on cultural and medical facilities.

5.3.2 Optimal range: threshold effects of street design and density, and linear negative correlation of accessibility

In the influence mechanism of green travel behavior, the functional facility type of supermarket is significantly influenced by multidimensional spatial and behavioral factors. OD distance is the most influential factor, and after 2300 meters, the probability of green travel significantly decreases, indicating a significant decrease in residents' willingness to walk or ride after exceeding 2.3 kilometers. Secondly, the density of parking facilities (Dparking) shows an increasing trend of green travel within the range of 92-180/km², reflecting that moderate traffic control can help suppress the advantages of motor vehicles and encourage slow driving behavior. The third important variable is the terrain elevation fluctuation (dem_range1), which enhances the green travel response between 16.9-28 meters, indicating that blocks with medium elevation differences are more friendly to green travel, possibly related to the openness of the field of view and spatial cognition.

In addition, the length of the street (length_me) within the two scales of 250-360 meters and 550-580 meters is conducive to green travel, revealing its effect on the perceived rhythm of the street; Areas with lower INTmea (50-83) are more conducive to walking choices; The bicycle lane setting (bimrlen1) exhibits a certain guiding effect in the range of 0.5-0.8; The green preference attitude (greprefer0) as a subjective variable has a moderating effect in the model; The residential building density (Drebd) and non-residential density (Dnorebd) constitute the basic population and functional support for green travel within the ranges of 0.9-1.2 and 0.5-1.2, respectively; And the continuity of the street (contin_u_me) enhances the consistency and accessibility of travel paths within the range of 0.35-0.64.

In summary, the behavioral mechanism of green travel in supermarkets emphasizes the triple coupling logic of "spatial proximity traffic regulation micro terrain suitability", and is also influenced by secondary support factors such as street structure and slow traffic facilities (Figure 5.35).

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

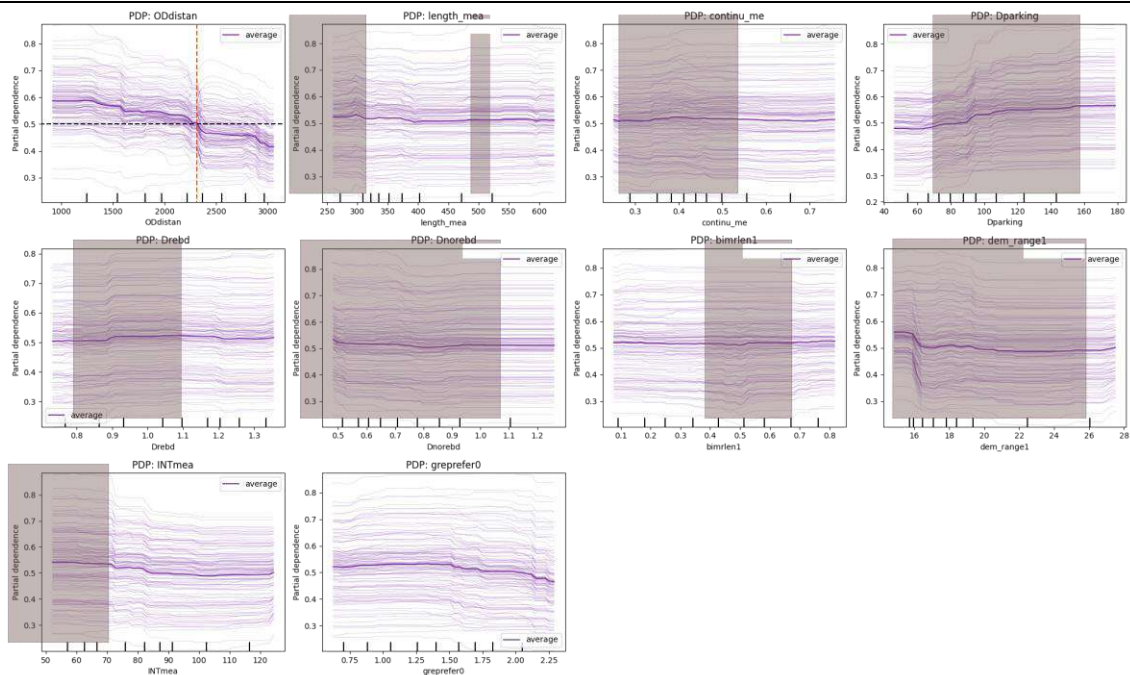


Figure 5.35 Partial Dependence Plots (PDP) of key features and supermarket green travel proportion

(gray represents the green travel promotion threshold, the same below)

For functional health facilities such as hospitals and clinics, their green travel is mainly influenced by the following three factors:

OD distance remains the most core variable, and green travel behavior has decreased beyond 2250 meters, indicating that hospitals should be located within the medium distance living circle that residents can walk/ride within. The facility support function mix (Fnmix4mea) and function mix (Fnmixmea) both have a positive impact, with optimal ranges of 0.35-0.55 and 0.88-1.5, respectively. This indicates that hospitals should be located in areas with high functional complexity to enhance travel convenience and service chain integration capabilities. The density of bus stops (Dbus_stop) in the range of 24-55/km² is conducive to green travel and highly compatible with the bus and walking travel chain, suggesting that hospitals should be embedded in public transportation friendly areas.

Other factors such as residential building density (Drebd, 0.91-1.6), accessibility of transportation (cartool, biketool), and street scale characteristics (heitwidmea, dem_range1) also provide environmental support for green travel, but their impact is relatively minor.

Overall, the green travel of hospital facilities relies on a composite path of "medium

distance accessibility + mixed functions + public transportation support", and should be prioritized for embedding in urban sub center areas with high agglomeration and slow traffic public transportation integration conditions to achieve fair and efficient service acquisition and travel mode transformation.

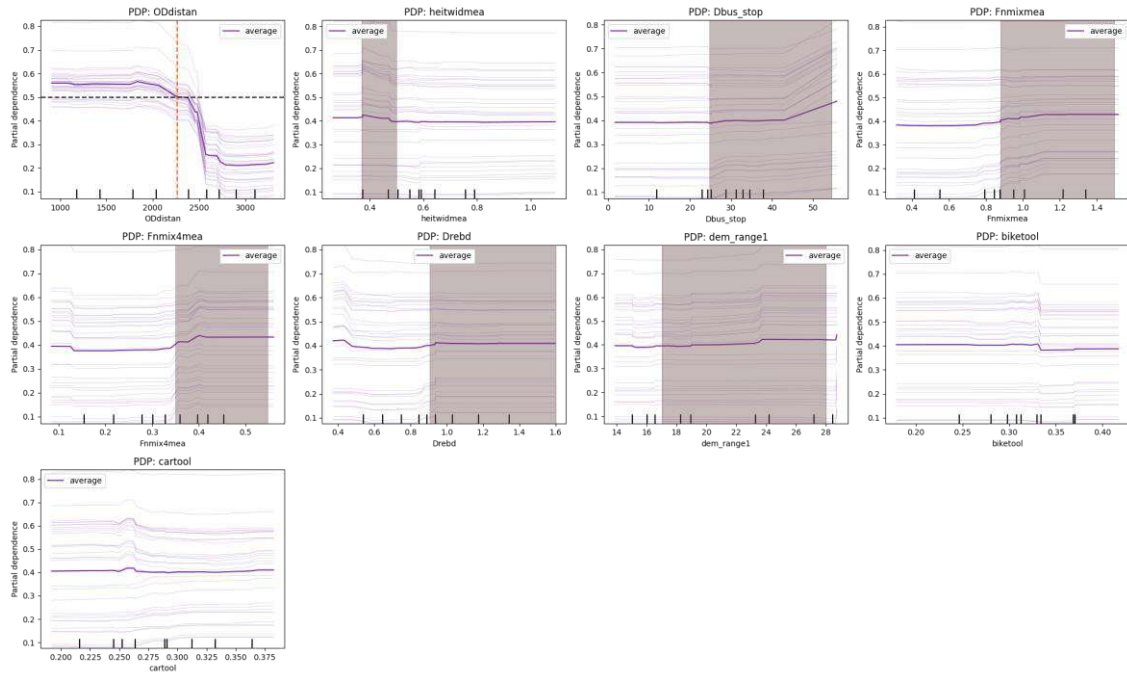


Figure 5.36 PDP of key features and health service center facilities green travel proportion

For educational facilities such as junior high schools, green travel behavior is mainly influenced by the following factors:

ODdistan is the decisive factor for green travel, and walking/cycling behavior is more common within 1500 meters, indicating that junior high schools should prioritize layout near residential quarters to ensure close accessibility for school-age groups. The accessibility of motor vehicles (cartool) has a certain inhibitory effect on green travel, suggesting that good slow infrastructure and traffic grading management can better promote green educational behavior. The spatial characteristics such as street level (rdclmea, 1.57-2.4) and non-residential building density (Dnorebd, 0.3-0.57) significantly enhance the possibility of green travel within an appropriate range, indicating that environments with low traffic conflicts and strong street functional living are more suitable for students' education.

Other influencing factors include the density of functional facilities (DALL14), the sense of street enclosure (heimeamea, 24.5-27.5 meters), and the amount of greenery

(ndvi_me, 0.1993-0.22 meters), which together construct a comprehensive street microenvironment conducive to students' green travel. Overall, the green travel of junior high school facilities relies on a composite microenvironment of "close range + weak traffic flow + residential blocks", and should be prioritized for embedding in street systems with minimal traffic conflicts and strong functional continuity to ensure school safety and stimulate green commuting behavior.

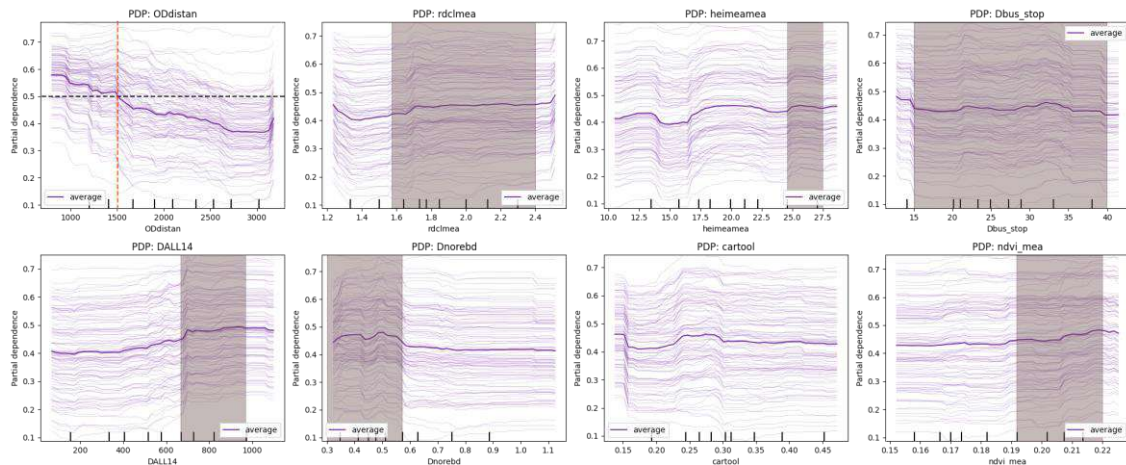


Figure 5.37 PDP of key features and middle school green travel proportion

For cultural activity facilities, the primary influencing factor for green travel behavior is ODdistance. Studies have shown that when the travel distance between residents and cultural activity facilities is controlled within 1800 meters, the likelihood of choosing to walk or ride significantly increases. This distance threshold reveals that cultural destinations have moderate functional attractiveness and psychological tolerance radius, making them suitable for layout in the middle ring of the living circle.

Secondly, the average density of leisure facilities (DLEISURE, 9.4-20) and educational facilities (DEDU, 0.42-2.0) showed positive effects in the higher range, indicating that cultural facilities are often co located with composite public services, and mixed functional environments help to enhance the diversity of travel purposes and path linkage. The terrain undulation (dem_range1, 12.5-15.9) tends to be gentle, the street width (width_me, 33-45 meters) is moderate, and the green level (ndvi_me, 0.16-0.19) meets the standard, all of which contribute to creating a pleasant travel experience. In addition, non-residential building density (Dnorebd) and green travel preference (greprefer0) are also important moderating variables, while street length (length_me, 250-400 meters) has auxiliary significance in improving accessibility rhythm and spatial perception.

Overall, the dependence of cultural activity facilities on green travel emphasizes the combination of environmental atmosphere and functional complexity, making it a typical "experience oriented" green travel node.

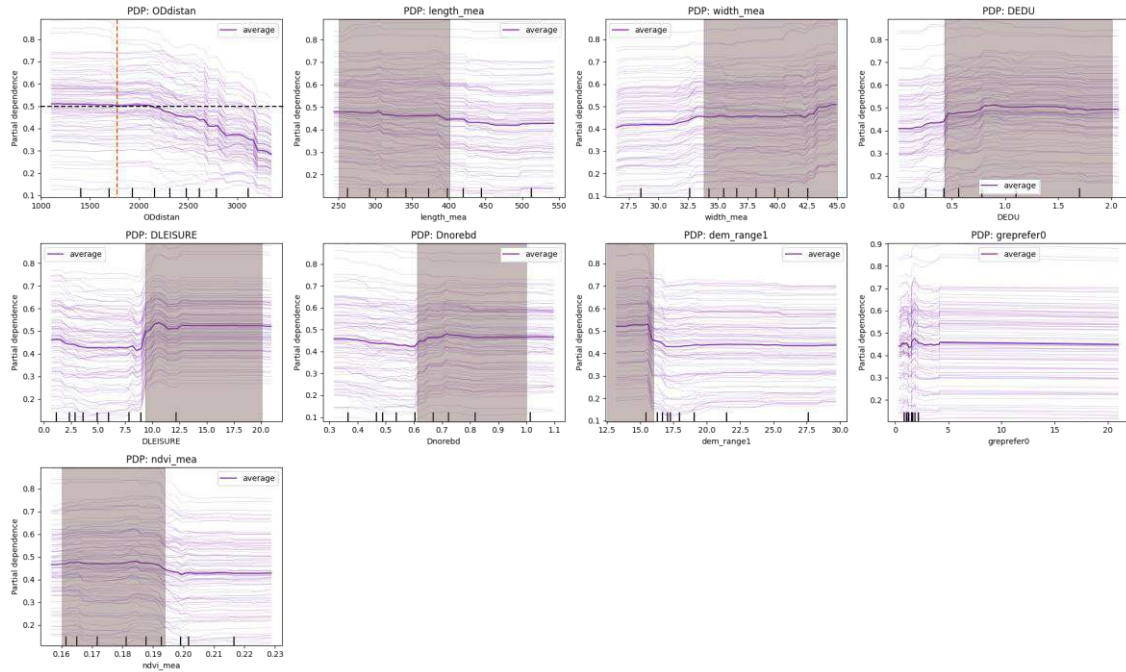


Figure 5.38 PDP of key features and cultural activity center green travel proportion

For facilities such as parks, squares, and scenic spots, green travel is mainly influenced by ODdistance, density of health facilities (DHEALTH), and terrain slope (slope_mea1).

Green travel has significantly decreased within a range of 1700 meters, indicating that such facilities should be located within the middle distance circle of residents. DHEALTH is beneficial for green travel in the 60-78/km² range, indicating that the supply of surrounding health services helps to build a healthy and friendly travel environment. The average slope between 2.2-2.48 shows the best performance, indicating that mild undulating environments are more attractive for walking.

Other factors such as street integration (INTmea, 40-80), bike lane design (bimlen1, 0.39-0.7), bus density (Dbus_stop, 10-22), street enclosure (heimeamea, 22.9-30 meters), and undulating range (dem_range1, 14-20) also provide support for green travel within a certain range, but their effects are relatively minor. Overall, the green travel of park facilities relies on the comprehensive environmental configuration of "medium distance + gentle slope + high green feeling", and should prioritize the coordinated optimization

of such environmental composite indicators in the urban open space system.

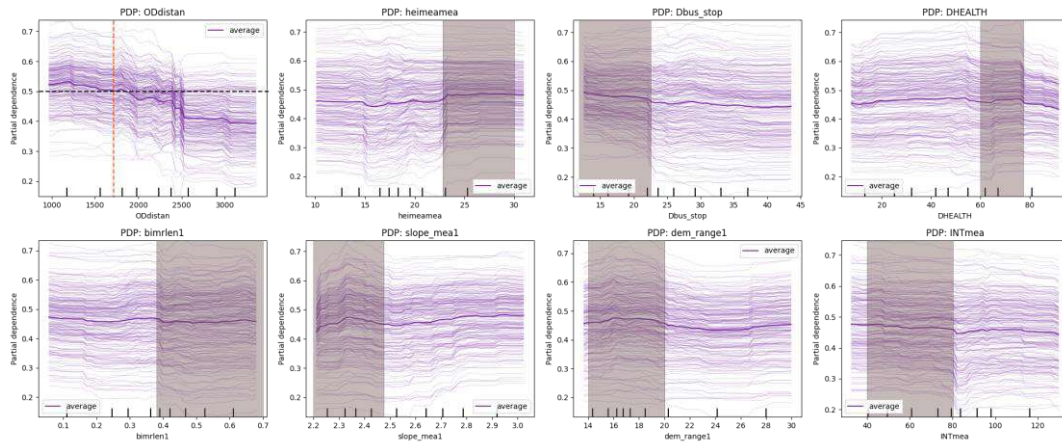


Figure 5.39 PDP of key features and park square attraction green travel proportion

For primary schools, which are basic educational facilities, green travel is mainly influenced by ODdistance, bus stop density (D_{bus_stop}), and non-residential building density (D_{norebd}). Green travel is relatively low in the 1850 meter range, indicating that the layout of primary schools should be controlled within a closer range of general education. D_{bus_stop} promotes green travel in the 30-40/km² range, strengthening the composite travel mode of "walking/cycling + public transportation". D_{norebd} shows a positive response within the range of 0.3-1.0, indicating that primary schools should be located in streets with moderate non-residential functional mix, which helps to form a stable learning and living environment.

Other influencing factors include street aspect ratio (heitwidmea, 0.4-0.61), residential building density (D_{rebd}, 0.8-1.18), street width (width_meal, 27-34.7 meters), integration degree (INTmea, 50-80), and basic education infrastructure density (DEDU, 1-2.5), all of which provide green travel support within specific ranges, but have a secondary effect compared to the first three variables.

Overall, the green travel of primary school facilities relies on a composite environmental support of "proximity + school safety + spatial intimacy". Therefore, it is necessary to systematically introduce composite intervention strategies such as pedestrian scale control, street interface optimization, and traffic coordination design in the construction of child friendly spaces in the living circle.

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

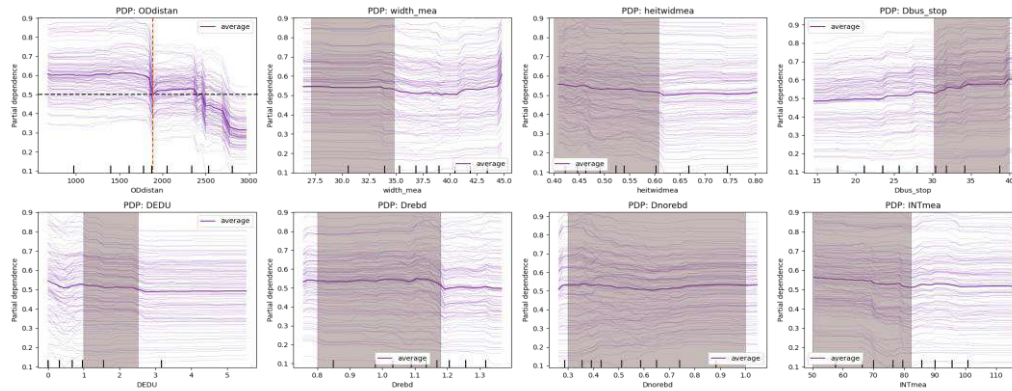


Figure 5.40 PDP of key features and primary school green travel proportion

For the vegetable market, a high-frequency lifestyle service facility, its green travel is most significantly affected by ODdistance, terrain undulation (dem_range1), and greenery level (ndvi_mea).

Within a range of about 2200 meters, the probability of green travel has significantly decreased, indicating that the vegetable market should be located within a medium distance service circle that is accessible by residents through a combination of cycling and walking. The terrain undulation within the range of 16.9-22 meters is conducive to green travel, indicating that moderate elevation differences may be related to the distribution of plateaus or visual coherence in residential quarters. NDVI exhibits a response characteristic of "first decreasing and then increasing" within the range of 0.19-0.22, indicating that moderate greenery can create a comfortable and non-intrusive street environment for such facilities.

Other influencing factors include the setting of bike lanes (bimrlen1, 0.24-0.7), slope (slope_meal, 2.4-2.7), non-residential building density (Dnrebld, 0.3-0.53), road grade (rdclmea, 1.2-1.6), street width and building height, and other street form variables, reflecting the high dependence of such facilities on accessibility, clear access paths, and spatial perception.

Overall, the green travel of vegetable market facilities relies on a mixed environment configuration of "medium distance + gentle slope + micro enclosure + moderate green volume". A street network that integrates accessibility and recognizability should be constructed in residential service centers to maximize the synergistic effect of high-frequency life services and green travel.

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

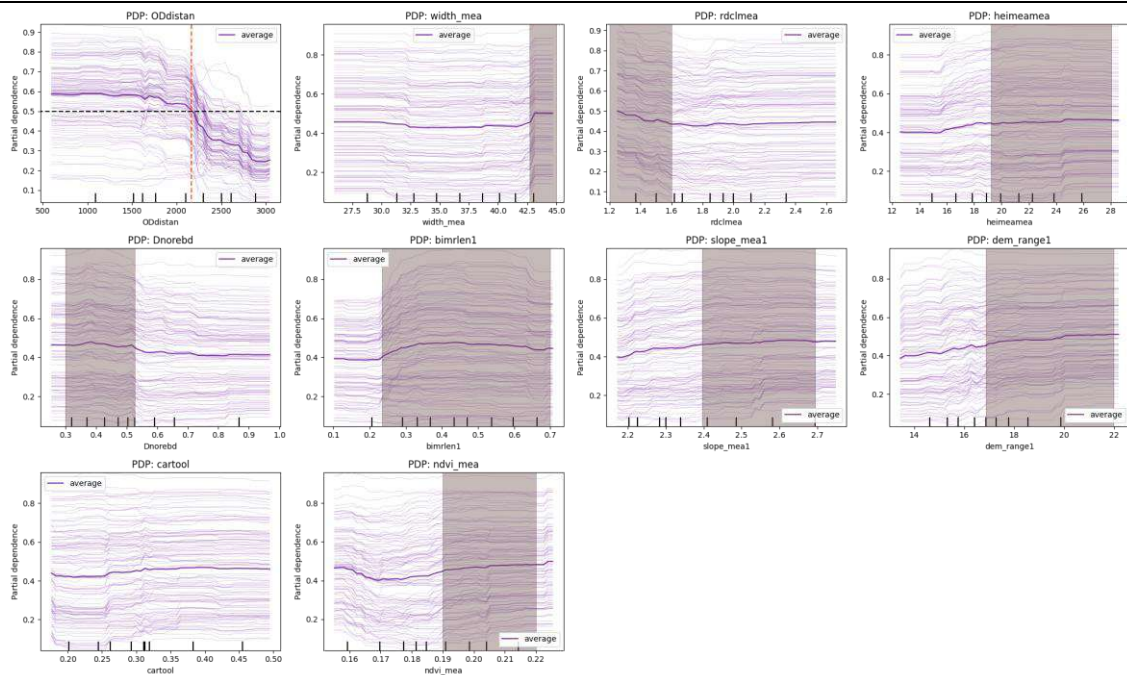


Figure 5.41 PDP of key features and vegetable market green travel proportion

For the embedded high-frequency use facility of community commerce, its green travel is mainly driven by three factors: ODdistance, integration degree (INTmea), and terrain undulation (dem_range1).

When the travel distance is less than 1200 meters, the probability of green travel significantly increases, indicating that community commercial travel is highly sensitive to distance and should be prioritized in close range living circles that prioritize walking or cycling. The integration degree in the range of 60-93 creates favorable network nesting conditions for green travel, which is conducive to the formation of slow-moving directional spaces within the block. The terrain undulations between 17.5-23 meters also have a promoting effect on green travel, indicating that community commercial sites are suitable for areas with moderate terrain and strong path continuity.

Other factors such as cartool, continuity of streets (continuity, 0.45-0.8), road grade (rdclmea, 1.6-2.4), density of parking facilities (Dparking, 65-140), and bike lane layout (bimrlen1, 0.2-0.51) all contribute to the model, especially street continuity and functional mix, which are crucial for creating a "neighborhood style" green travel environment. In addition, the green index (ndvi_mea) forms a response peak in the range of 0.15-0.17, reflecting the subtle balance demand of community commerce between "moderate greening and high recognizability".

Overall, the green travel of community commercial facilities highly relies on the spatial environment combination of "short distance + strong integration + medium green + street continuity". A clear, coherent, and accessible slow-moving network should be formed in the community texture to enhance residents' green accessibility and behavioral willingness towards daily shopping destinations.

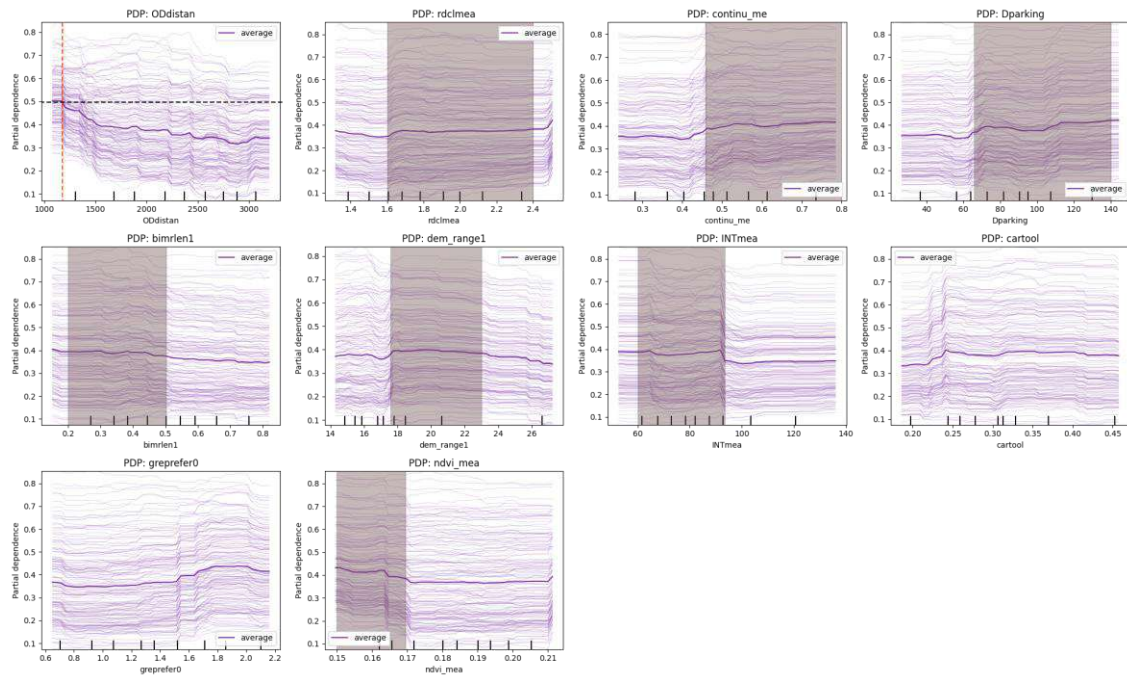


Figure 5.42 PDP of key features and community commercial outlets green travel proportion

5.3.3 Classification: cross-type consistency, cross-type differential and single-type specific variable

In this section, independent variables are categorized to analyze the differences in the influence mechanisms across facility types. The impact of these variables and the corresponding green travel thresholds for the eight facilities are shown in the Figure 5.43. Based on their impact mechanisms, these variables are divided into three categories: Cross type consistency variables - the impact mechanism of common factors is the same; Cross type differential variables - common factors have different influencing mechanisms; Single type specific variable - unique influencing factors of a certain type of facility.

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

	Supermarket	Health service center	Middle school	Cultural activity center	Park_square_attr actions	Primary school	Vegetable market	Community commercial outlets	Intersection	Class
Dparking	(92.123, 180)							(64.9613, 140)	(92.12, 140.00)	A
length_mea	(250,360) ∪ (550,580)			(250, 400)					(250, 360)	
INTmea	(50, 83.1182)				(40, 80.2407)	(50, 80.2407)		(60, 93.4983)	(60.00, 80.24)	
greprefer0										
Drebd	(0.8973, 1.2)	(0.9093, 1.6)				(0.8, 1.1802)			(0.91, 1.18)	
contin_u_me	(0.35, 0.6359)							(0.4515,0.8)	(0.45, 0.64)	
cartool										
heltwidmea		(0.3742, 0.5)				(0.4,0.6106)			(0.40, 0.50)	
heimeamea			(24.4978, 27.5)		(22.8667, 30)		(19.338, 28)		(24.50, 27.50)	
DEDU				(0.4224, 2.0)		(1.2.5)			(1.00, 2.00)	
slope_mea1					(2.2, 2.4803)		(2.3921, 2.7)		(2.39, 2.48)	B
dem_range1	(16.9088, 28)	(16.9088, 28)		(12.5, 15.9172)	(14,20)		(16.9141, 22)	(17.4715, 23)	∅	
bimrlen1	(0.5151, 0.8)				(0.3874, 0.7)		(0.2381, 0.7)	(0.2, 0.5067)	∅	
Dnorebd	(0.5,1.2)		(0.3, 0.5687)	(0.6189, 1.0)		(0.3,1.0)	(0.3, 0.5309)		∅	
Dbus_stop		(24.4086, 55)	(15, 40)		(10, 22.6679)	(30.1651, 40)			∅	
rdclmea			(1.5704, 2.4)				(1.2, 1.6)	(1.6, 2.4)	∅	
ndvi_mea			(0.1993, 0.22)	(0.16, 0.1935)			(0.19,0.22)	(0.15, 0.1694)	∅	
width_mea				(33, 45)		(27, 34.6799)	(42.7679, 45)		∅	
Fnmix4mea		(0.35,0.55)							(0.35, 0.55)	
Fnmixmea		(0.8787,1.5)							(0.88, 1.50)	
biketool										C
DALL14			(677.9324, 1000)						(677.93, 1000.00)	
DLEISURE				(9.3875, 20)					(9.39, 20.00)	
DHEALTH					(60, 77.9794)				(60.00, 77.98)	

Figure 5.43 Effects of various independent variables on eight types of facilities and green travel threshold

(1) Cross-Type Consistency Variables (Category A)

These variables have similar correlation trends or positive ranges for green travel proportions across different facility types (Category A factors), making them crucial in urban planning and design. For example, **OD travel distance**, **Integration degree**, and **most of street design variables** exhibit consistent effects across facility types, as detailed below.

ODdistan (OD Travel Distance)

- **ODdistan** is a core common factor influencing green travel across all facility types. The study finds that green travel probability significantly decreases as travel distance increases, with specific green travel thresholds (the distance at which the green travel proportion reaches 50%) varying across facility types. For example:
 - For educational facilities, the green travel probability significantly drops in the

1500-1850 meter range, showing that school-age populations are highly sensitive to travel distances.

- For commercial facilities, community commerce has a sensitivity to green travel at distances under 1200 meters, while supermarkets and supermarkets can tolerate distances of 2200 meters and 2300 meters, respectively.
- For healthcare facilities, such as hospitals and clinics, the green travel threshold is up to 2250 meters, indicating that despite the widespread distribution of health services, residents can maintain more than 50% green travel even at larger distances.
- In leisure facilities, the green travel threshold for parks, scenic spots, and city squares is 0-1700 meters, indicating that public recreational spaces have moderate distance attractiveness for walking or cycling. The green travel threshold for cultural activity centers (such as museums, cultural centers, etc.) is 0-1800 meters, reflecting the moderate coverage of cultural facilities in residents' daily activities.

Table 5.4 Green travel distance thresholds for eight facility types

Feature	Threshold distance (m)	Positive range by distance (m)
Primary schools	1850	(0, 1850)
Middle schools	1500	(0, 1500)
Vegetable markets	2200	(0, 2200)
Supermarkets	2300	(0, 2300)
Community commercial	1200	(0, 1200)
Hospitals, clinics, and health facilities	2250	(0, 2250)
Parks, attractions, and squares	1700	(0, 1700)
Cultural activity center facilities	1800	(0, 1800)

In addition to travel distance, Class A factors include six other spatial independent variables, and their impact mechanisms and intersection intervals on green travel of various facilities are as follows (Figure 5.43).

Length_mea

- Street length (length_mea) enhances green travel for both malls and cultural activity centers in the 250-360 meter range. For malls, a secondary peak occurs in the 550-580 meter range, indicating that shorter street segments optimize walking rhythms and path

controllability, thereby reducing fatigue and shortening psychological distance perception.

Continu_me

- Street wall continuity in the range of 0.45–0.64 significantly increases the green travel probability for malls and community commercial outlets, enhancing environmental readability and street-commercial interactions.

Heitwidmea

- A street width-to-height ratio (heitwidmea) between 0.4–0.5 creates a common peak for both hospitals and primary schools, offering visual safety and spatial order suitable for medical and educational settings.

Drebd

- Residential building density peaks for malls, hospitals, and primary schools in the ranges of approximately 0.9–1.2, indicating that moderate to high residential building density promotes green travel across different facility types.

INTmea

- Integration degree enhances green travel for parks, primary schools, community commerce, and malls when the integration is low (50–80), proving that street structures with moderate integration reduce traffic disturbances and environmental noise, triggering walking and cycling behaviors.

Heimeamea

- Average building height (heimeamea) exhibits positive responses in the 24.5–27.5 meters range for primary schools, parks, and vegetable markets, creating a vibrant street environment conducive to high pedestrian flow and promoting green travel.

The above variables have a relatively consistent impact on green travel for multiple types of facilities, collectively forming a spatial impact spectrum of green travel behavior.

(2) Cross-Type Variability Variables (Category B)

These variables show significantly different trends in green travel influence across facility types (Category B factors). Including factors such as NDVI_mea (greenery ratio) and Dnoebd (non-residential building plot ratio). as follows:

In the cross type difference variables, the impact of normalized vegetation index (NDVI_mea) on green travel shows significant heterogeneity among different facility types: educational facilities (such as junior high schools) have a significantly higher probability of green travel in the green volume range of 0.1993-0.22, while cultural facilities perform similarly in the range of 0.16-0.1935. Moderate greening enhances

spatial attractiveness and pedestrian comfort by creating a quiet and continuous street interface; Community commercial preferences have a low green volume (0.15-0.1694), and its "green but not obscured" environment is more conducive to forming a continuous and recognizable commercial atmosphere; The vegetable market exhibits non-linear response characteristics, with relatively high green volume in the range of 0.19-0.22. Too low or too high green volume may weaken its convenience and perceptual guidance. Its "U-shaped" greening effect indicates that an initial increase in green volume may weaken path explicit recognition, but subsequent improvement will stimulate the second stage of green travel preference through environmental quality and visual appeal.

The impact of non-residential building plot ratio (Dnorebd) shows structural differences: the probability of green travel in junior high schools and vegetable markets significantly increases in the low non-residential density range (0.30-0.57 and 0.30-0.53), reflecting their preference for "lifestyle" street environments (strong accessibility and high path predictability at low densities); Cultural facilities perform better in the medium to high density range (0.62-1.00), relying on activity nodes and public communication scenes provided by composite functional spaces to extend the travel chain; Primary schools and supermarkets respond smoothly within the density range, indicating that their green travel relies more on fundamental factors such as distance and street scale. This difference arises from the non-linear interaction between functional "interference" and accessibility - high non-residential density may lead to complex traffic and noisy environments, inhibiting slow access to daily facilities, while moderate density enhances the attractiveness of green travel through the shaping of vibrant neighborhoods. Excessive "hollowing out" or functionally singular structures weaken the potential for green travel, highlighting the differentiated role of spatial mixing in different types of facilities (Figure 5.43).

(3) Facility-Specific Variables (Category C)

This type of variable is a sensitive variable specific to a certain type of facility, referred to as Class C factor, including functional mix (Fnmix4mea, Fnmixmea), enjoying facility density (DLEISURE), caring facility density (DHEALTH), etc.

Fnmix4mea (Mean Mixing Degree of Street Support Tasks): The green travel behavior of medical facilities is highly dependent on the street system's ability to support specific tasks. When the street support task mix (Fnmix4mea) is in the range of 0.35-0.55, the probability of residents walking or cycling to hospitals and clinics significantly

increases. Compared to other types of facilities, medical travel is more sensitive to the adaptability of street system tasks, reflecting its strong dependence on path clarity and accessibility. This phenomenon indicates that medical travel needs to achieve precise matching of task objectives at the street level to reduce travel uncertainty and path costs. High task adaptability enhances green travel frequency by creating a "micro center" living environment, reducing dependence on motor vehicles, and strengthening functional complexity. In planning practice, medical service facilities should be prioritized in street systems with high task support to optimize the green travel environment.

Fnmixmea (Mean of Street Function Mix): Medical travel also shows a significant response to street function mix (Fnmixmea). When the indicator is in the range of 0.88-1.50, the probability of residents walking or cycling to hospitals and clinics significantly increases, indicating that high functional diversity streets have a positive guiding effect on medical travel. Streets with higher levels of mixing usually have stronger composite service capabilities, allowing residents to meet other living needs while completing medical tasks, thereby reducing single travel costs and enhancing convenience. In addition, mixed streets enhance the sense of safety and user stickiness of slow traffic through crowd gathering and social environment creation, which is a key supporting factor in building a green travel friendly network.

DALL14 (Average Density of Street Comprehensive Facilities): The proportion of green travel for junior high school trips significantly increases within the range of 677.93-1000/km² of street comprehensive facility density (DALL14), indicating that facility supply at this density level can effectively support the green shift of educational travel. High density facilities enhance the vitality of pedestrian flow and environmental safety, and improve the social surveillance and comfort of adolescent travel routes. At the same time, the gathering of life service nodes around educational facilities can meet multiple needs in daily routes such as transportation and learning, thereby enhancing the attractiveness and practical feasibility of green travel.

DLEISURE (Street Enjoying facility Density): The probability of green travel in cultural activity centers significantly increases within the enjoying facility density (DLEISURE) range of 9.39-20/km², revealing the positive role of leisure resource aggregation in stimulating cultural travel. High density leisure facilities enhance the multifunctionality and environmental attractiveness of the area, encouraging residents to choose green ways such as walking or cycling. The leisure function of gathering not only

enhances the visual continuity and perceptual experience of the street, but also provides rich social and stopping opportunities, reduces the perceived burden of commuting, and promotes the occurrence of non-motorized vehicles and walking travel.

DHEALTH (Street Caring facility Density): The proportion of green travel in park and square facilities significantly increases within the range of caring facility density (DHEALTH) of 60-77.98/km², indicating the supporting role of health service supply in leisure green travel. The dense distribution of health facilities enhances the correlation between street vitality and physical activity, creating a health oriented travel atmosphere. Residents frequently come into contact with facilities such as pharmacies and gyms on the path leading to the park square, which not only enhances the usability and service of the street, but also strengthens the connection between health awareness and slow accessibility. The continuous distribution of facilities further enhances the vitality and safety of streets, and promotes the realization of green travel at both psychological and functional levels (Figure 5.43).

5.4 Clustering results: four street clusters and characteristics

Given the heterogeneity in the green travel thresholds across different facility types for **Category B factors**, this study performs a **cluster analysis** based on the common features of **Category A** and the specific features of **Category C**. The clustering results ensure that the streets within each cluster exhibit consistent performance regarding the **A** and **C** class factors, thereby providing a basis for differentiated planning (Table 5.5). The variables used for clustering were strictly selected according to the "be base for cluster" criteria: only those variables with practical design operability or functional adaptability were included, while some variables (such as **D_parking**, **slope_mean**, **INT**, **Func_mix_4**) were excluded based on the following considerations:

- **Non-Core Design Elements:** For example, **D_parking** (parking lot density) is not a destination facility and is weakly correlated with street space design.
- **Uncontrollable Variables:** **Slope_mean**, as a natural topographical attribute, has limited intervention space for design.
- **Practical Feasibility:** **Integration degree (INT)** is an abstract spatial syntax index that is challenging to directly translate into planning practice.
- **Redundancy Control:** **Func_mix_4 (functional mix degree)** and **Func_mix**

(functional mix) are highly correlated, and including both could interfere with clustering stability.

To enhance the applicability of the conclusions, the study converts the road conditions in the rectangular area defined by the **OD flow cluster** into street-scale threshold values for optimization guidance. This conversion ensures that the values are directly comparable, maintaining practicality in street design. For example, if all major roads within a rectangular area meet the 250–360 meter threshold, the **mean length of major roads** for that area will fall within the same range. More intuitively, when there is only one major road in the rectangle, the length of that single road will serve as the **mean length** for the area. This transformation ensures that street design can directly align with threshold requirements, avoiding practical disconnections caused by data aggregation.

Table 5.5 Street variables serving as the basis for subsequent clustering

Variable_rect	Variable_road	Intersection	type	be base for cluster
Dparking	D_parking	(92.12,140.00)	A	no
dem_range1	_range		B	no
length_mea	length	(250,360)	A	yes
INTmea	INT	(60.00,80.24)	A	no
bimrlen1	bikeyes		B	no
Drebd	D_re_bd	(0.91,1.18)	A	yes
Dnorebd	D_no_re_bd		B	no
continuity_me	continuity	(0.45,0.64)	A	yes
Fnmix4mea	Func_mix_4	(0.35,0.55)	C	no
Dbus_stop	D_bus_stop		B	no
Fnmixmea	Func_mix	(0.88,1.50)	C	yes
heitwidmea	heitwid	(0.40,0.50)	A	yes
rdclmea	road_class		B	no
DALL14	D_ALL14	(677.93,1000.00)	C	yes
heimeamea	heimea	(24.50,27.50)	A	yes
ndvi_mea	ndvi_mean		B	no
DLEISURE	D_LEISURE	(9.39,20.00)	C	yes
DEDU	D_EDU	(1.00,2.00)	A	yes
width_mea	width		B	no
DHEALTH	D_HEALTH	(60.00,77.98)	C	yes
slope_mea1	_mean	(2.39,2.48)	A	no

5.4.1 Central high and peripheral low clusters as spatial characteristics

Using hierarchical clustering, four distinct street types with high differentiation were identified, numbered 0, 1, 2, and 3. Based on the characteristics of each type, the streets were named as follows: **Multi-dimensional Promotion Type**, **Suitable Length Type**, **Enclosed Leisure Type**, and **Green Travel Support Deficient Type**. The clustering results and their spatial distribution are summarized in the table and figure. The number of streets for each type is distributed as follows: among 3,641 main roads, Type 0 includes 1,189 streets, Type 1 includes 336 streets, Type 2 includes 192 streets, and Type 3 includes 1,924 streets, showing a clear imbalance in distribution. Type 3 has the largest number, while Type 2 has the smallest.

Table 5.6 Number of streets for each type

Type	Name	Location	Count
Type 0	Multi-dimensional Promotion Type	Old town and city center	1,189
Type 1	Suitable Length Type	Southern New District	336
Type 2	Enclosed Leisure Type	City center	192
Type 3	Green Travel Support Deficient Type	City edge, suburbs, riverside	1,924

Spatial Distribution

- **Type 0 streets:** These streets are primarily located in the old town and city center, with a continuous distribution along the two main development axes of the city, **Xinhua Road** and **Jianshe Road**.
- **Type 1 streets:** Found mostly in the southern new district, particularly in the **Rentai Li District**, this area is influenced by the new planning concept of "**small blocks and dense road networks**". The residential blocks are about 300 meters in size, making these streets shorter compared to those in other parts of Tangshan.
- **Type 2 streets:** These streets are primarily located along one of the city's development axes, **Xinhua Road**, and are mostly east-west streets.
- **Type 3 streets:** These streets are mainly found on the edge of the city, in suburban areas, and along riverbanks. They tend to be longer and more winding.

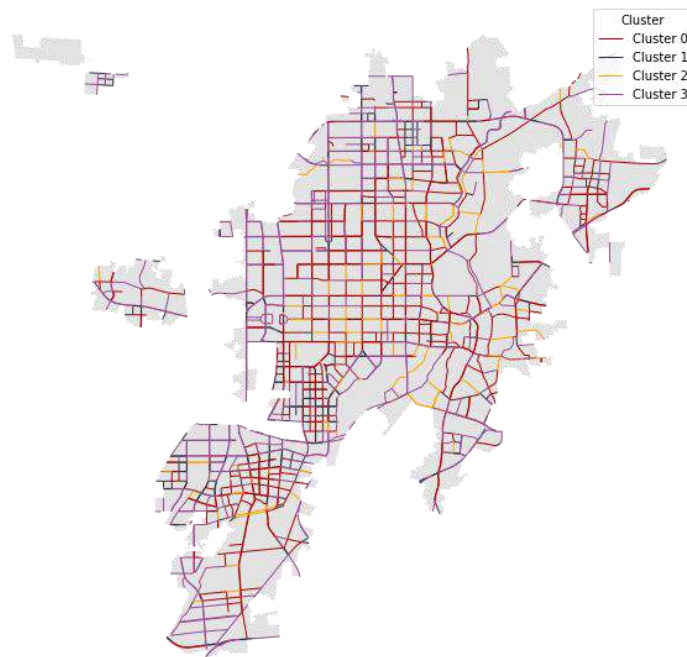


Figure 5.44 Spatial distribution of each street type

5.4.2 Optimal design and density as green travel-driven layout characteristics

Based on the clustering results (table), the green travel promotion features of the four street types can be described as follows:

(1) Cluster 0 (Multidimensional Promotion Street, $n=1,189$)

This type of street performs the most outstandingly in terms of functional mix (0.53) and street continuity (0.33). The residential building plot ratio (0.28), street length (0.16), and caring facility density (0.08) are also located in the green promotion zone, indicating that it has good comprehensive spatial support capacity and can provide stable structural support for green travel. It is possible to strengthen the construction of its ecological environment and educational facilities appropriately.

(2) Cluster 1 (Street length dominant street, $n=336$)

Almost all (99.7%) of these streets fall within the optimal street length range, representing the efficiency of green travel. However, their green promotion features in terms of functional mix (0.01), continuity (0.01), and facility density are almost missing, reflecting the shortcomings of a single structure. It is suitable to introduce composite facilities or improve enclosure and continuity to enhance the stickiness of use.

(3) Cluster 2 (high enclosure leisure potential street), n=192)

The best performance is in terms of aspect ratio (0.68) and enjoying facility density (0.42), indicating that this type of street has a strong sense of enclosure and concentrated leisure resources, which is conducive to attracting green travel activities; The functional mix ratio (0.16) and plot ratio (0.13) also have a certain foundation, and have the potential to further stimulate green behavior through functional reinforcement.

(4) Cluster 3 (green support for missing streets, n=1,924)

All indicators are 0, indicating that this type of street has not met the standards for all green travel promotion elements, and belongs to a typical street with insufficient spatial environment support. There is an urgent need for systematic intervention and reconstruction from multiple dimensions such as street scale, architectural form, facility configuration, and spatial mixing.

Key Differentiators

The primary differences between these street types lie in the **design** and **density** indicators, such as **main road length**, **street wall continuity**, and **aspect ratio**. These variables collectively shape the green travel potential of different types of streets and their priority for renovation.

Table 5.7 Green travel promotion features of each street type

(Values close to 1 indicate promotion, while values closer to 0 indicate non-promotion)

clu ster	leng th10	D_re _bd1 0	contin uity10	heit wid1 0	heim ea10	D_E DÜ1 0	Func_ mix10	D_AL L1410	D_LEIS URE10	D_HEA LTH10
0	0.16	0.28	0.33	0.07	0.09	0	0.53	0.18	0.03	0.08
1	1	0.12	0.01	0.1	0	0	0.01	0.08	0	0.01
2	0	0.12	0.04	0.68	0.02	0	0.16	0	0.42	0.01
3	0	0	0	0	0	0	0	0	0	0

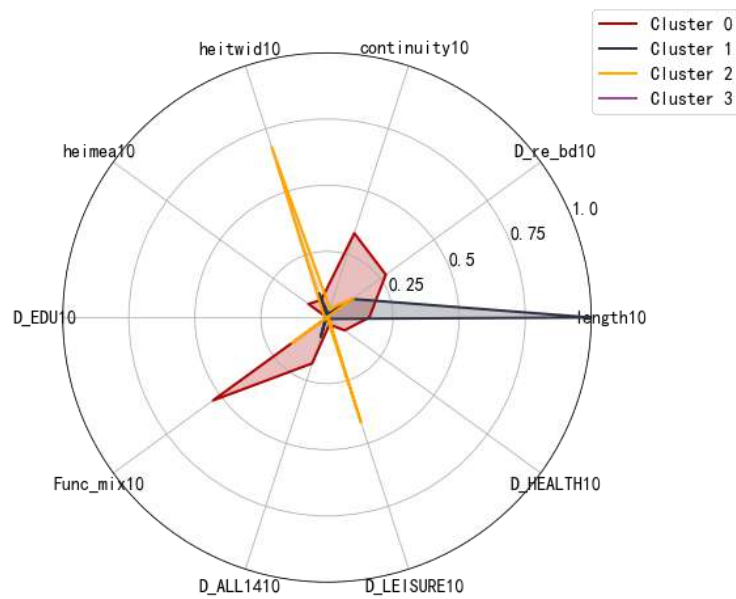


Figure 5.45 Radar chart of green travel promotion features for each street type

(This chart visualizes the values of each feature for the four street types. Values close to 1 promote green travel, while values closer to 0 indicate a lack of support for green travel.)

5.4.3 Typical streets

This study selects two representative streets from each category (Figure) and utilizes GIS for three-dimensional spatial visualization to concretize the characteristics.

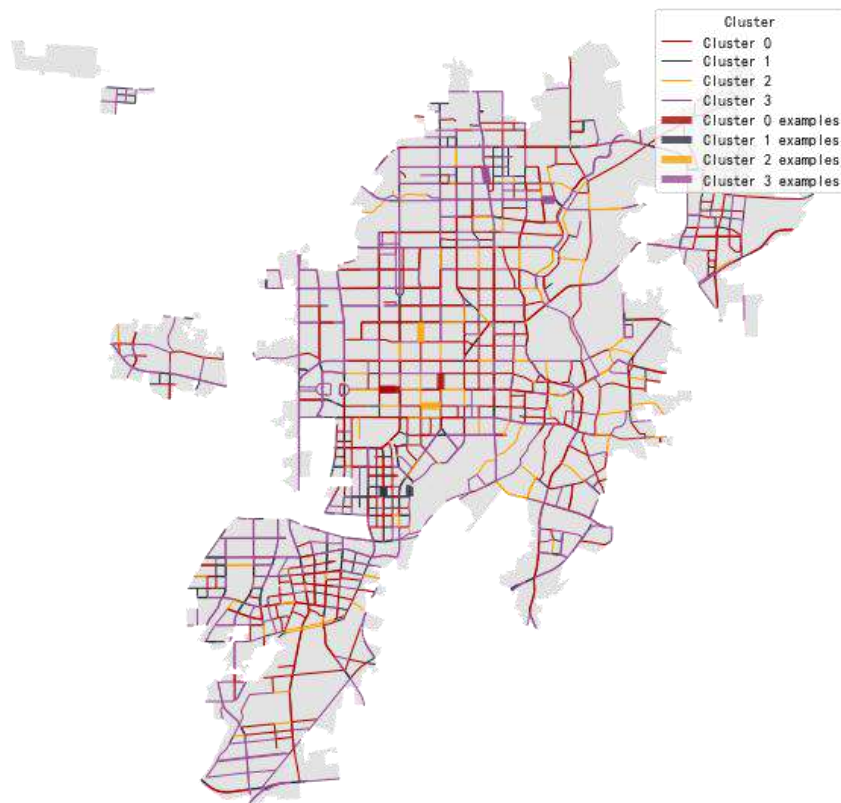


Figure 5.46 Spatial location diagram of typical streets

This typical street (psttID = 3227) belongs to Cluster 0, the "Multi-dimensional Promotion (gable-side) Type" category, and exhibits significant green travel support features. Among various indicators, this street falls within the green travel promotion threshold range for two key variables: residential building density (0.98) and facility functional mix (1.22). These values reflect a well-structured residential density and the provision of multifunctional services, which can effectively enhance destination accessibility and street vitality. Observations from the street view further validate the spatial perception advantages formed by the party wall building interface, functional mixed layout, and continuous facades. While other variables such as street segment length (511.34m), continuity (0.87), and street width ratio (0.62) do not fall within the promotion range, they still demonstrate moderate spatial support, forming an important background for the overall green travel-oriented pattern.

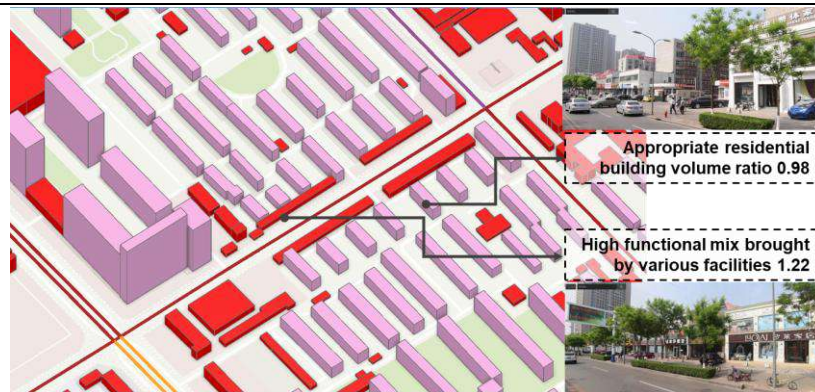


Figure 5.47 Cluster 0 Multi-dimensional Promotion Street (gable-side)

Table 5.8 Cluster 0 Multi-dimensional Promotion Street (gable-side) variable values, comparison with optimal range values, and promotion effect

(1 indicates promotion, represented in purple; 0 indicates no promotion, represented in gray, the same applies to the following.)

cl us te r 0	Leng th (m)	D_re _bd	conti nuity	heitw id	heime a (m)	D_E DU (/k m2)	Func _mix	D_ALL 14 (/km2)	D_LE ISUR E (/k m2)	D_HE ALTH (/km 2)
Po siti ve ran ge	(25 0,36 0)	(0.9 1,1.1 8)	(0.4 5,0.6 4)	(0.4 0,0.5 0)	(24. 50,27. 50)	(1.0 0,2.0 0)	(0.8 8,1.5 0)	(677.9 3,1000. 00)	(9.3 9,20. 00)	(60. 00,77. 98)
ps ttl D 32 27 ue l or 0	511. 34	0.98	0.87	0.62	18.09	0	1.22	1834.3	0	118.8 9
	0	1	0	0	0	0	1	0	0	0

Another typical street from Cluster 0 (non-gable side) includes streets with **psttID** 13007 and 14504, located along the main axis of Tangshan's development—Xinhuadao, just two blocks from the train station. These two streets exhibit good wall-side continuity (continuity values of 0.63 and 0.52, both within the green promotion range), making them continuous and easy to traverse. Along these streets, facilities display a high level of functional mix (Func_mix values of 1.36 and 1.35), and the overall facility density is also high (D_ALL14 values of 864.63 and 781.99 /km²), contributing to the stimulation of multiple travel motivations and a reduction in commuting distances. Despite the street

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scale (length), building enclosure perception (height), and residential building volume ratio (D_re_bd) not falling within the green promotion threshold, these streets still exhibit good spatial support potential overall.

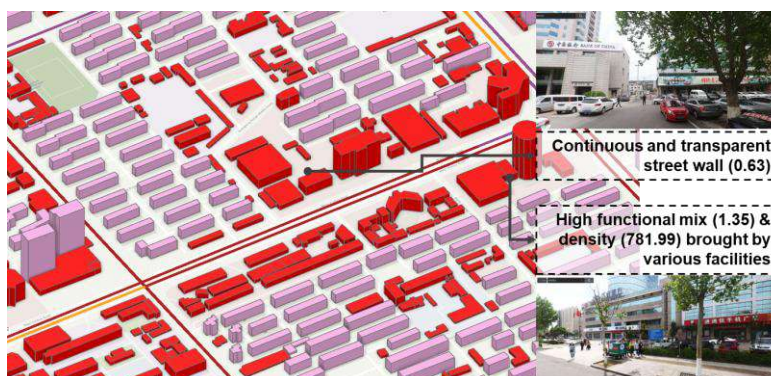


Figure 5.48 Cluster 0 Multi-dimensional Promotion Street (non-gable side)

Table 5.9 Cluster 0 Multi-dimensional Promotion Street (non-gable) variable values, comparison of promoting interval values, and promotion effects

clus ter 0		Leng th (m)	D_re _bd (0.9 1,1.1 8)	conti nuity (0.4 5,0.6 4)	heitw id (0.4 0,0.5 0)	heime a (m) (24. 50,27. 50)	D_E DU (/k m2) (1.0 0,2.0 0)	Func _mix (0.8 8,1.5 0)	D_ALL 14 (/km2) (677.9 3,1000. 00)	D_LEI SURE (/km 2) (9.39 ,20.00)	D_HE ALTH (/km 2) (60.0 0,77.9 8)
pstit ID 130 07 (u p)	Posi tive ran ge	(25 0,36 0)	(0.9 1,1.1 8)	(0.4 5,0.6 4)	(0.4 0,0.5 0)	(24. 50,27. 50)	(1.0 0,2.0 0)	(0.8 8,1.5 0)	(677.9 3,1000. 00)	(9.39 ,20.00)	(60.0 0,77.9 8)
	Va ria ble val ue	535. 53	1.21	0.63	0.83	21.6	0	1.36	864.63	0	114.2
pstit ID 145 04 (d ow n)	1 or 0	0	0	1	0	0	0	1	1	0	0
	Va ria ble val ue	664. 21	1.21	0.52	0.91	23	0	1.35	781.99	0	80.9
	1 or 0	0	0	1	0	0	0	1	1	0	0

Cluster 1: Street Length-dominated Street (gable side) Typical Representative. The typical characteristic of these streets is that their main street length falls within the green promotion range (250–360 meters), such as the representative streets with psttID 3394 and 10661, which have lengths of 302.81 meters and 301.94 meters, respectively. These streets are located in the southern 新区 (new district), displaying a more compact street scale, matching the spacing of the facilities, which helps to enhance the street's walkability and visual guidance. However, other key variables (such as functional mixing, facility density, and enclosure) do not fall into the green promotion threshold, indicating that while the structural scale of these streets holds promotional potential, further improvements in functional mixing and facility adequacy are needed to enhance their green travel support capacity.

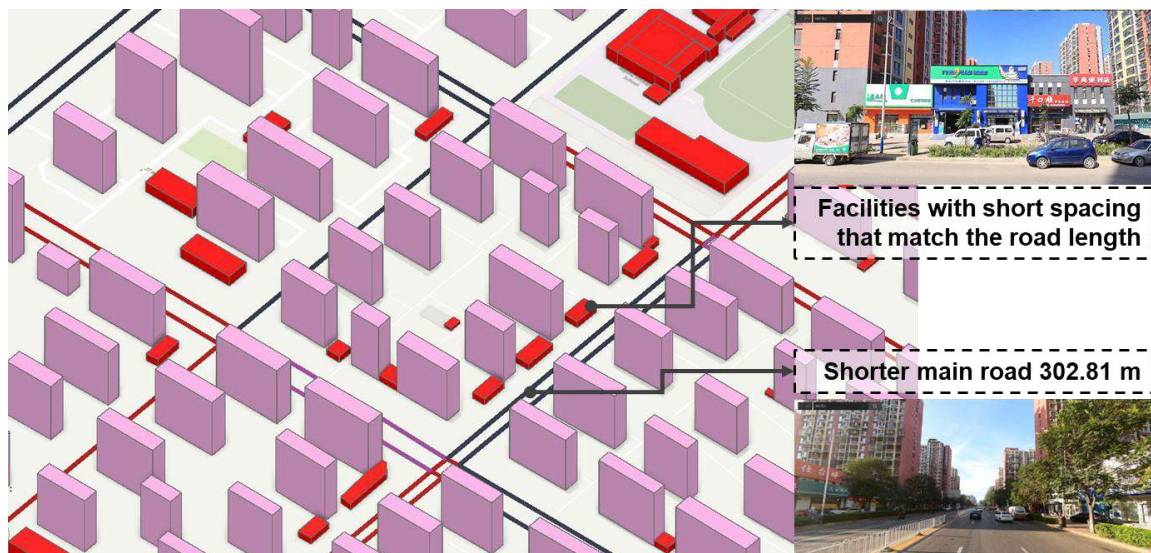


Figure 5.49 Cluster 1 Street Length-dominated Street (gable side)

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Table 5.10 Cluster 1 Street Length-dominated Street (gable side) variable values, comparison of promoting interval values, and promotion effects

clus ter 1		Len gth (m)	D_re _bd	conti nuity	heightw id	heime a (m)	D_E DÜ (/k m2)	Func _mix	D_ALL 14 (/km2)	D_L EISU RE (/k m2)	D_HE ALTH (/km 2)
	Posi tive range	(25 0,36 0)	(0. 91,1. 18)	(0. 45,0. 64)	(0. 40,0. 50)	(24. 50,27. 50)	(1. 00,2. 00)	(0. 88,1. 50)	(677. 93,100 0.00)	(9.3 9,20. 00)	(60. 00,77. 98)
pstt ID 339 4	Va ria ble val ue (u p)	302. 81	1.66	0.75	1.06	34	0	1.56	2051.5 7	0	210.4 2
	1 or 0	1	0	0	0	0	0	0	0	0	0
pstt ID 106 61	Va ria ble val ue (d own n)	301. 94	1.66	0.67	1.1	35.29	0	1.61	2003.5 6	0	237.2 6
	1 or 0	1	0	0	0	0	0	0	0	0	0

Another Typical Street (psttID = 3567) belongs to Cluster 1, a " Street Length-dominated Street (non-gable side)," located in the southern riverfront (new district). Its main street length is 347.41 meters, which falls within the green travel promotion range, and its height-to-width ratio (0.42) also meets the standard for a good spatial enclosure. Although the street's residential volume ratio (0.55), functional mix, and facility density do not reach the green travel support threshold, the short residential spacing along the street and the compact overall structure provide strong potential for walkability continuity.

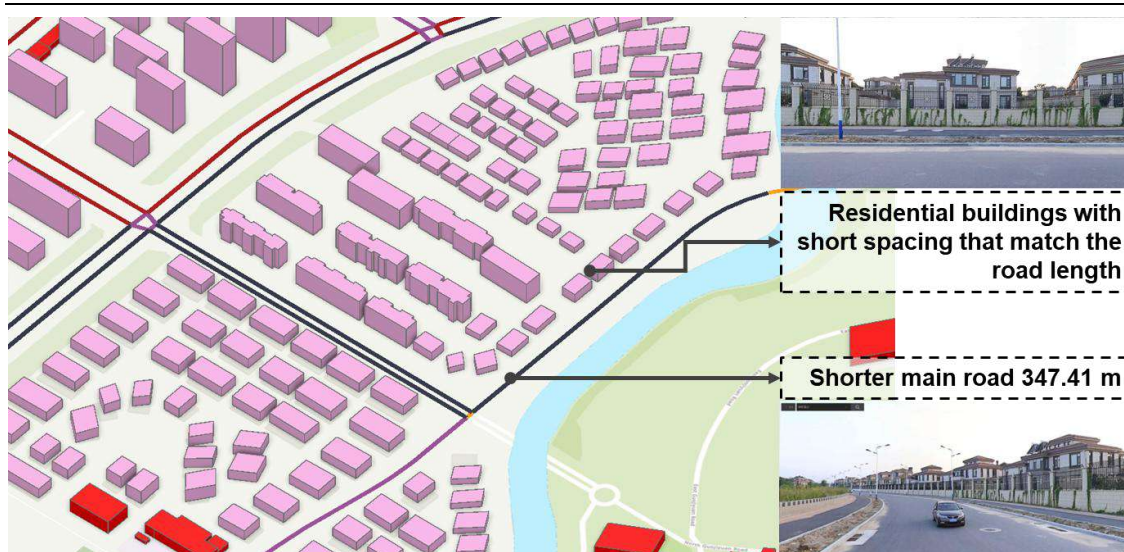


Figure 5.50 Cluster 1 Street Length-dominated Street (non-gable side)

Table 5.11 Cluster 1 Street Length-dominated Street (non-gable side) variable values, comparison of promoting interval values, and promotion effects

cl us te r 1	Leng th (m)	D_re _bd	conti nuity	heitw id	heime a (m)	D_E DU (/k m2)	Func _mix	D_ALL 14 (/km2)	D_LE ISUR E (/k m2)	D_HE ALTH (/km 2)
Po siti ve ran ge	(25 0,36 0)	(0.9 1,1.1 8)	(0.4 5,0.6 4)	(0.4 0,0.5 0)	(24. 50,27. 50)	(1.0 0,2.0 0)	(0.8 8,1.5 0)	(677.9 3,1000. 00)	(9.3 9,20. 00)	(60. 00,77. 98)
ps ttl D 35 67	347. 41	0.55	0.45	0.42	11	0	0	0	0	0
1 or 0	1	0	0	1	0	0	0	0	0	0

Cluster 2 Typical Street (psttID = 6887) is classified as a "Enclosure Leisure Street (non-gable side)." This street is located in the old town, and its height-to-width ratio is 0.41, falling within the green travel promotion range, creating a good spatial enclosure. Additionally, its enjoying facility density reaches 13.85 per km², which also enters the green support threshold, demonstrating strong daily appeal. Moreover, the building volume ratio (0.92) meets the green threshold, reflecting a higher residential intensity. However, the street length is relatively long (644.57 meters), and the overall functional

mix and facility density do not meet the support threshold, which should be enhanced in future urban renewal efforts.

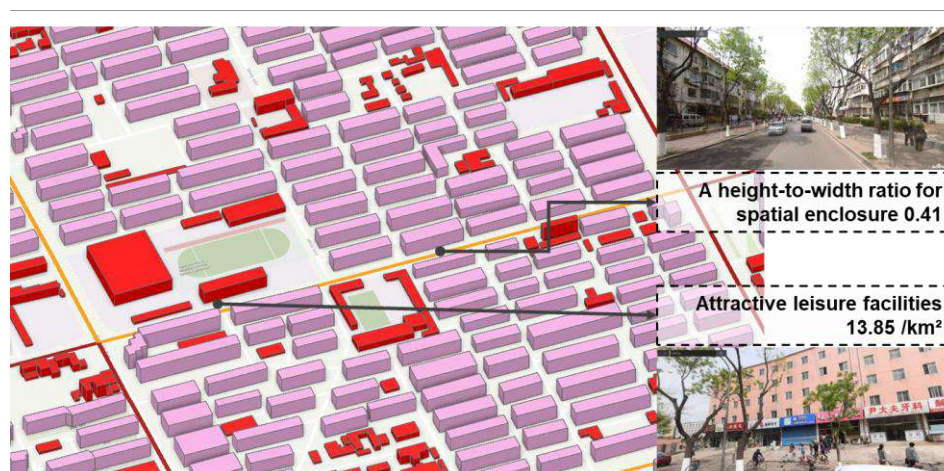


Figure 5.51 Cluster 2 Enclosure Leisure Street (non-gable side)

Table 5.12 Cluster 2 Enclosure Leisure Street (non-gable side) variable values, comparison with promoting range values, and promotion effect

cl us te r 2	Leng th (m)	D_re _bd	conti nuity	heiw id	heime a (m)	D_E DU (/k m2)	Func _mix	D_ALL 14 (/km2)	D_LE ISUR E (/k m2)	D_HE ALTH (/km 2)
Po siti ve ran ge	(25 0,36 0)	(0.9 1,1.1 8)	(0.4 5,0.6 4)	(0.4 0,0.5 0)	(24. 50,27. 50)	(1.0 0,2.0 0)	(0.8 8,1.5 0)	(677.9 3,1000. 00)	(9.3 9,20. 00)	(60. 00,77. 98)
ps ttl D 68 87 ble val ue	644. 57	0.92	0.83	0.41	12.73	0	1.77	1052.57	13.85	83.1
1 or 0	0	1	0	1	0	0	0	0	1	0

The typical street psttID=3595 belongs to Cluster 2 type, which is a "Enclosure Leisure Street (gable side)". The street is located in the old city area, with an average building height of 27.5 meters, at the upper limit of the green travel support threshold. The spatial hierarchy is staggered, forming a certain degree of spatial enclosure and visual continuity, showcasing the unique street wall interface characteristics on the mountain wall side. At the same time, the density of leisure facilities is 14.03 units/km², located in

the green support zone, which helps attract purposeful and leisure travel. Although the street length (635.14 meters) is relatively long, the functional mix and facility density do not meet the supporting standards, the coordinated configuration of its spatial interface and leisure functions provides key support for green travel, reflecting the typical feature of streets that enhance the attractiveness of green travel through the linkage of form and facilities.

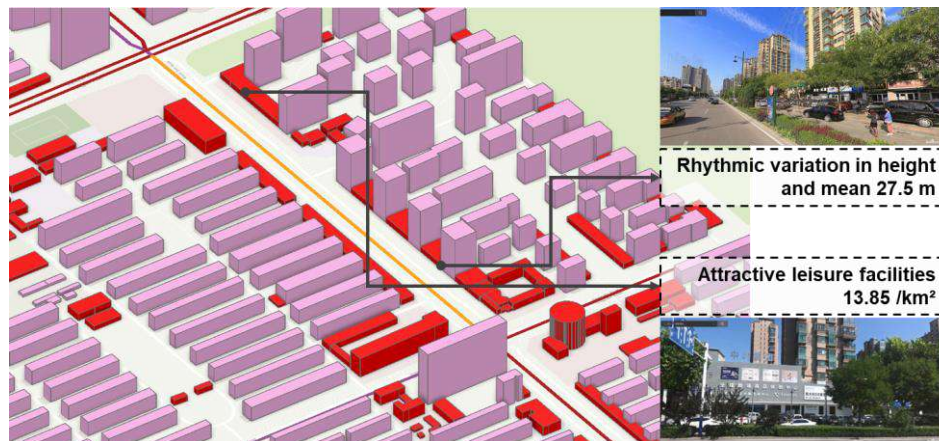


Figure 5.52 Cluster 2 Enclosure Leisure Street (gable-side)

Table 5.13 Cluster 2 Enclosure Leisure Street (gable-side) variable values, comparison with promoting range values, and promotion effect

cl us te r 2	Leng th (m)	D_re _bd	conti nuity	heitw id	heime a (m)	D_E DU (/k m2)	Func _mix	D_ALL 14 (/km2)	D_LE ISUR E (/k m2)	D_HE ALTH (/km 2)
Po siti ve ran ge	(25 0,36 0)	(0.9 1,1.1 8)	(0.4 5,0.6 4)	(0.4 0,0.5 0)	(24. 50,27. 50)	(1.0 0,2.0 0)	(0.8 8,1.5 0)	(677.9 3,1000. 00)	(9.3 9,20. 00)	(60. 00,77. 98)
ps ttl D 35 95 val ue	635. 14	1.67	0.67	0.62	27.5	14.03	1.64	1108.59	14.03	98.23
1 or 0	0	0	0	0	1	0	0	0	1	0

Streets **psttID = 3297** and **psttID = 3687** represent the " Deficient-support Street (non-gable side)" streets. These streets are located where the main tributary of the

Hehuang River branches out. The main characteristic of these streets is the extreme lack of service facilities. The spatial form and functional indicators fail to meet the green travel support threshold. Street **psttID = 3297** has a facility density of only 61.51/km², far below the threshold for green facilities, and its functional mix (0.66) and street continuity (0.34) are noticeably lacking.

Street **psttID = 3687** shows even more extreme characteristics, as its service facility land has been overtaken by the river, with almost all indicators at 0 or very low values. This shows a complete detachment from the green travel support structure. These streets urgently need comprehensive interventions to repair their service functions and spatial interfaces. Strategies such as facility addition and waterfront interface optimization should be considered in urban renewal.



Figure 5.53 Cluster 3 Deficient-support Street (non-gable side)

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Table 5.14 Cluster 3 Deficient-support Street (non-gable side) variable values, comparative optimal range values, and promotion effects

clu ste r 3		Len gth (m)	D_re _bd	conti nuity	heit wid	heime a (m)	D_E DU (/km 2)	Func _mix	D_ALL 14 (/km2)	D_LE ISUR E (/km2)	D_HE ALT H (/km2)
	Pos itiv e ran ge	- 250 ,36 0	(0.91 ,1.18)	(0.45 ,0.64)	(0.40 ,0.50)	(24.50 ,27.50)	(1.00 ,2.00)	(0.88 ,1.50)	(677.93, 1000.00)	(9.39, 20.00)	(60.00 ,77.98)
pst tID 36 87 (up)	Var iabl e val ue	408 .55	0.56	0.03	0.08	4.29	0	0	20.58	0	0
	1 or 0	0	0	0	0	0	0	0	0	0	0
pst tID 32 97 (do wn)	Var iabl e val ue	410 .34	0.57	0.34	0.13	7.5	0	0.66	61.51	0	0
	1 or 0	0	0	0	0	0	0	0	0	0	0

Streets represented by psttID=5849 and 5175 exhibit typical characteristics of "loose space and lack of functionality", making them one of the street types with the least support for green travel (Cluster 3 Deficient-support Street, gable-side). Located near the industrial park in the northern new area of Tangshan, under the influence of urban sprawl and low-density development, the residential density is low and there are many non-living service facilities, such as logistics and warehousing facilities. The length of its main roads exceeds 530 meters, much higher than the suitable range for green travel (250-360 meters), resulting in large spacing and poor accessibility of facilities along the street. In terms of spatial form, due to the presence of setback spaces and large open spaces, the aspect ratios of the two streets are only 0.24 and 0.11 respectively, making it difficult to form a good sense of enclosure, and the building height is also far below the threshold for green travel.

In addition, the functional mix and service facility density of such streets are almost zero (for example, the D_ALL14 with psttID=5175 is only 49.01/km²), which cannot support the convenience and continuity of daily life. This type of street urgently needs

comprehensive intervention measures such as supplementing facilities, strengthening interfaces, and optimizing scales to activate its green travel potential.



Figure 5.54 Cluster 3 Deficient-support Street (gable-side)

Table 5.15 Cluster 3 Deficient-support Street (gable-side) variable values, comparison optimal range values, and promotion effects

cluster 3	Length (m)	D_re_b d	continuity	heightwid	heime (m)	D_ED U (/km ²)	Func_mix	D_ALL14 (/km ²)	D_LEI SURE (/km ²)	D_HEA LTH (/km ²)
Positive range	(250, 360)	(0.91, 1.18)	(0.45, 0.64)	(0.40, 0.50)	(24.50, 27.50)	(1.00, 2.00)	(0.88, 1.50)	(677.93, 1000.00)	(9.39, 20.00)	(60.00, 77.98)
psttI D 5849 (up value)	542.64	0.75	0.1	0.24	11.62	0	0	112.89	0	0
1 or 0	0	0	0	0	0	0	0	0	0	0
psttI D 5175 (down value)	534.72	0.76	0.18	0.11	5.62	0	0	49.01	0	0
1 or 0	0	0	0	0	0	0	0	0	0	0

5.5 Validation

Given that distance variables have a significant impact on green travel for various

single category facilities, the paper first verifies their thresholds. By comparing with existing literature on the threshold of walking and cycling distance (Table 5.16), the suggestions for green travel service radius for various facilities proposed in this paper are consistent with existing research patterns and have strong universality and rationality.

Numerous empirical studies both domestically and internationally have found that the comprehensive proportion of green travel (walking and cycling) has significantly decreased between 1 to 3 kilometers. The walking distance is mostly concentrated between 400-800 meters, and the usage rate rapidly decreases after exceeding 1200 meters. In terms of cycling, most studies have shown that 1-2 kilometers is the most common travel distance for cycling, and the proportion of cycling begins to significantly decline after exceeding 2.5-3 kilometers.

Regarding different types of facilities, the walking and cycling distance thresholds for health and leisure facilities are longer than those for other types of facilities. Supermarkets have a longer walking and cycling distance threshold than convenience stores. The results are consistent with international research.

Table 5.16 Consistency between distance thresholds in the thesis research findings and existing research results

Facility	Threshold distance (m)	Positive range by distance (m)	All existing studies	Existing walking studies	Existing cycling studies
Primary schools	1850	(0, 1850)	According to the research by Nelson et al. (2008), the proportion of walking and cycling trips approaches 50% at approximately 2.2 km, with most walkers residing within 1.9 km of primary schools and cyclists within 3.2 km (Nelson et al., 2008).	For primary school trips, both the Youden index (0.808) and efficiency (1.792) methods identified 1,475 m as the optimal threshold, below which walking is preferred and beyond which driving is favored; this threshold aligns closely with the 1.5 km threshold proposed by D'Haese et al. (2011) and Silva et al. (2020) in studies on walking to primary schools (Clark et al., 2016); the mean walking distance for primary and junior high school commutes is approximately 757 m (Larsen et al., 2010).	Based on the distance decay function, the cycling share for primary and junior high school commutes declines from 50% to 25% within the 0–2,000 m range (Iacono et al., 2008); the mean cycling distance for these commutes is approximately 2,273 m (Larsen et al., 2010).
Junior high schools	1500	(0, 1500)			
Vegetable markets	2200	(0, 2200)		In shopping trip scenarios, the mean walking distance is approximately 754 m (Larsen et al., 2010). According to the facility usage distance decay curve, the willingness to walk for shopping facility trips decays from 100% to 50% at around 600 m (Yang & Diez-Roux, 2012); more specifically, the 50% threshold for supermarket trips is 300–1,500 m, for convenience stores 300–750 m, and for vegetable markets 300–900 m (Lu Yintao, 2013).	Based on the multimodal distance decay function research by Iacono et al. (2008), the cycling proportion for shopping trips declines from 30% to 15% within the 0–1.5 km range (Iacono et al., 2008). The mean cycling distance for shopping trips is approximately 2.20 km (Larsen et al., 2010).
Supermarkets	2300	(0, 2300)			
Community commercial facilities	1200	(0, 1200)			

Table 5.16 Consistency between distance thresholds in the thesis research findings and existing research results (Continued)

Facility	Threshold distance (m)	Positive range by distance (m)	All existing studies	Existing walking studies	Existing cycling studies
Hospitals, clinics, and health facilities	2250	(0, 2250)	Iacono et al. (2008) found that walking distances for fitness purposes are significantly longer than those for other trip purposes (Iacono et al., 2008).	According to the facility usage distance decay curve, the willingness to walk for hospital facility trips declines from 100% to 50% within the range of approximately 300 m to 1,500 m (Yintao Lu, 2013).	
Parks, attractions, and squares	1700	(0, 1700)		According to the research by Yang and Diez-Roux (2012), the willingness to walk for leisure purposes decays from 100% to 50% at approximately 1.2 km (Yang & Diez-Roux, 2012). Based on the analysis of multimodal distance decay functions by Iacono et al. (2008), the walking proportion for enjoying facility trips decreases from 40% to 20% within the 0 km to approximately 1 km range (Iacono et al., 2008). Leisure walking trips decline from 12% to 6% within the 0 km to 0.7 km interval (Larsen et al., 2010). The average walking distance for leisure trips is approximately 0.86 km (Larsen et al., 2010; Yang & Diez-Roux, 2012).	According to the research by Iacono et al. (2008) on distance decay functions for different trip purposes, the cycling proportion for leisure trips decreases from 40% to 20% within the 0 to 2 km range (Iacono et al., 2008). The average cycling distance for leisure trips is approximately 3.36 km (Larsen et al., 2010).
Cultural activity center facilities	1800	(0, 1800)	Compared with other purposes, leisure walking exhibits significantly longer distances and durations (Yang & Diez-Roux, 2012).		

CHAPTER 5 CORRELATION BETWEEN SINGLE-TYPE GREEN TRAVEL MODE CHOICE AND FACILITY LAYOUT

Secondly, The findings of this study further corroborate existing literature by examining street-scale variables' green travel thresholds. As shown in the table, the identified ranges for street length (250–360 m), street wall continuity (0.45–0.64), aspect ratio (0.40–0.50), building height (24.5–27.5 m), residential and non-residential density, and greenery (NDVI 0.15–0.22) align closely with prior research (Table 5.17).

Table 5.17 Consistency between street-scale variables' thresholds in the thesis research findings and existing research results

Variable_road	The results of this paper	Existing research results
Street lengthlength	(250,360)	Pedestrians' preference for route lengths of 100–200 meters suggests they tend to avoid excessive street crossings. Cyclists also prefer shorter route lengths ^[158] (Liu et al., 2020).
Street wall continuitycontinuity	(0.45,0.64)	For each street, the street continuity is calculated as the total length of the nearest building whose long-side makes an angle of less than 30 degrees with the street centerline, divided by the total length of the road.
Street aspect ratioheitwid	(0.40,0.50)	Buildings should have fewer than six floors, 50% of shops should be street-facing, there should be more greenery, streetlights should be spaced 15 to 30 meters apart, there should be more crossing facilities, sidewalks/bicycle lanes should be wider, and traffic should be less congested ^[158] (Liu et al., 2020).
IntegrationINT	(60.00,80.24)	There was no significant correlation between land use mix and intersection density and integration. The correlation between complete walkability and SSW was 0.76 ($p < 0.001$). SSW was positively correlated with all walkability components except land use mix ^[159] (Koohsari et al., 2016).
Average height of street buildingsheimea	(24.50,27.50)	Pedestrians and cyclists have similar preferences for the following road sections: buildings with fewer than 6 floors, 50% street-facing shops, more green space, streetlights spaced between 15 and 30 meters, more crossing facilities, wider sidewalks/bike lanes, and less traffic congestion ^[158] (Liu et al., 2020).
Residential building density (Drebd)	(0.91,1.18)	Residents living in areas with lower land use structures and job-to-population ratios tend to walk longer distances ^[160] (Guzman et al., 2020).
Non-residential building density (Dnorebd)	(0.3, 1.2)	Pedestrians and cyclists have similar preferences for the following road sections: buildings with fewer than 6 floors, 50% street-facing shops, more green space, streetlights spaced between 15 and 30 meters, more crossing facilities, wider sidewalks/bike lanes, and less traffic congestion ^[158] (Liu et al., 2020).
Greening rate (ndvi_mea)	(0.15,0.22)	Within the 400- and 800-m buffer zones, greenery at eye level was significantly associated with higher walking probability and longer walking time ^[161] (Lu et al., 2018).

For instance, the optimal street length supports pedestrians' preference for short, uninterrupted routes, while the continuity and aspect ratio thresholds reflect design principles that enhance walkability and cyclability—such as low-rise buildings, active ground-floor uses, adequate lighting, and abundant greenery. Moreover, the positive association between green space and walking behavior within 400–800 m buffers reinforces the validity of the proposed service radii. These results collectively validate that the distance thresholds for different facility types—especially the longer thresholds for health/leisure and shopping facilities—are not only empirically sound but also consistent with international evidence on active travel behavior.

5.6 Summary

This chapter uses 31,301 residential-facility OD flow clusters of eight types as samples. Based on random forest regression and PDP local dependence analysis, it quantitatively identifies the importance, impact trend and promotion range of each facility layout variable in the OD flow cluster on the green travel proportion, compares the similarities and differences of the eight types of facility mechanisms, and clusters them to obtain typical street types.

Regression and PDP analysis revealed that green travel decisions exhibit a multi-dimensional coupling mechanism: "accessibility dominates, street design supports, and density and attitudes support." Among these, OD travel distance, within the accessibility dimension, was the most important of all facilities, reflecting residents' widespread sensitivity to travel time and space costs. Green travel intentions typically decline rapidly between 1.2 and 2.3 kilometers, with health and leisure facilities exhibiting longer critical distances. Road condition-design is a secondary factor, with indicators such as street length, integration, building aspect ratio, and wall continuity significantly increasing the proportion of green trips within specific intervals, indicating that street form and interface characteristics play a key role in influencing travel choices. Road condition-density plays a crucial role in structural support, with a moderate mix of functions and non-residential density contributing to a continuous and active travel environment.

Further, based on the PDP line diagram, the study categorizes influencing factors into three categories: Category A—factors that are common across facilities and have roughly consistent driving ranges (such as main road length, residential building volume

ratio, integration, street wall continuity, and aspect ratio), which recur across multiple facility types and are the core of planning optimization; Category B—factors that are common across facilities but have different driving ranges (such as greenery ratio and non-residential density); and Category C—sensitive factors unique to specific facilities (such as the density of leisure and health facilities). The importance of factors in categories A and C is significantly higher than that in category B, indicating that optimizing green travel within living areas is highly transferable and should be based on common thresholds as design constraints.

Based on whether the variables for major streets in categories A and C fall within the green travel promotion range, 3,641 streets were clustered into four typical types: ① Multidimensional Promoting Streets—excelling in functional mix, building intensity, and continuity, and possessing high levels of green travel support capabilities; ② Length-Dominant Streets—supporting green travel in terms of length, but with a single functional configuration, requiring comprehensive street renovation to enhance user experience; ③ Leisure Enclosure Streets—highly attractive in terms of enclosure and leisure facilities, suitable for slow-moving orientation improvements; and ④ Support-Deficient Streets—scores are significantly low in all dimensions, reflecting typical issues of loose structure and insufficient functionality. The spatial distribution of these types of streets shows significant geographic differentiation: Multidimensional Promoting Streets are concentrated in old urban areas and core districts, length-dominated Streets dominate small-block new districts, Leisure Enclosure Streets are predominantly located near waterfronts and parks, and Support-Deficient Streets are primarily located on the urban fringes and in transitional zones.

The core finding of this chapter is that it offers a behavior-centered basis for street green-travel-oriented planning and renewal, including street green planning threshold and green street samples. This chapter verifies the dominance of accessibility and the synergistic effect of road conditions, echoing the conclusions of the previous Chapter 4 on all-type facilities travel, and providing a basis for setting the dependent variables in the next Chapter 6 on the study of single-type facilities long-distance travel choice.

CHAPTER 6 CORRELATION BETWEEN SINGLE-TYPE LONG-DISTANCE TRAVEL CHOICE AND FACILITY LAYOUT

As demonstrated in the previous two chapters, the longer the trip, the lower the level of green travel. Therefore, to improve green travel, residents should reduce long-distance travel. Within a living circle, single-facility travel choices can be categorized as "travel destination choice"—corresponding to the "foregoing proximity for distant facilities"—and "travel decision outcome"—corresponding to excessively long average travel distances to such facilities. This chapter only touches on the discussion of the former in the selection of independent variable of facility layout, while the latter is the main line. Using 533 living circles containing supermarkets trips and 357 living circles containing vegetable markets trips as a sample, this study uses 30 single-facility layout indicators (such as the distance of the maximum supermarket and the distance of the nearest supermarket) as independent variables, and the average travel distance of residents to such facilities within a 15-minute cycling living circle as the dependent variable. Through XGBoost regression and SHAP interpretation analysis, this chapter reveals the impact of single-facility layout on average travel distance. Hierarchical clustering is then used to identify typical living circle layout patterns, providing actionable thresholds for urban facility optimization (Figure 6.1, Figure 6.2).

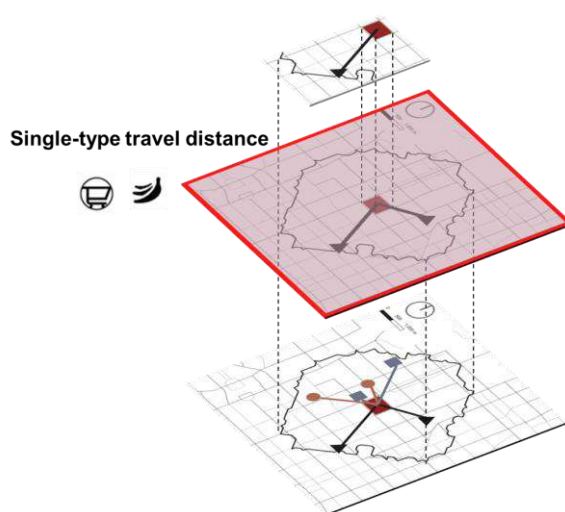


Figure 6.1 Travel behavior space of this chapter

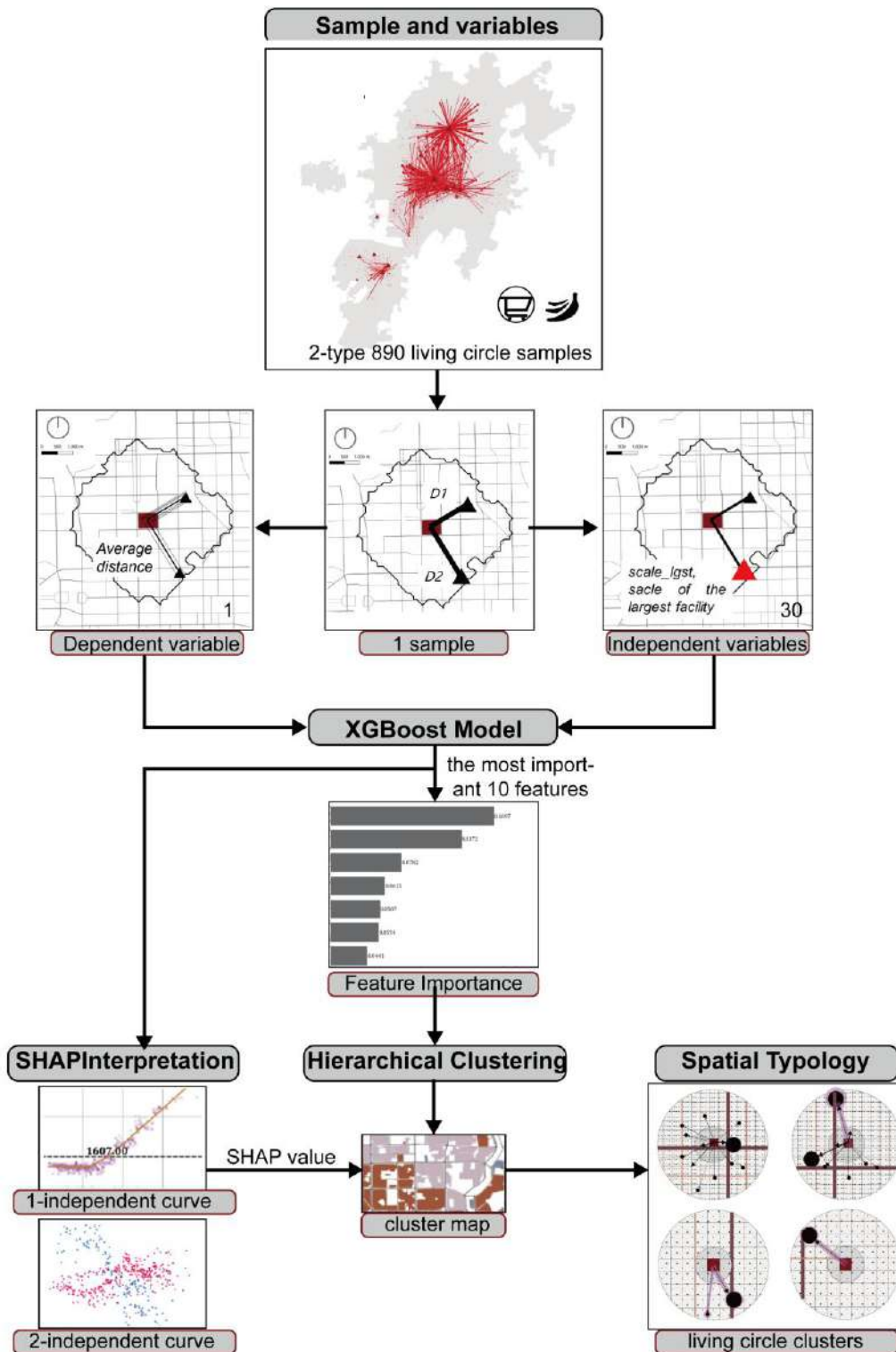


Figure 6.2 Framework of this chapter

Existing research on facility-related travel either focuses on the relationship between residential areas and facilities at the city scale, or examines facilities as the analytical unit to compare the spatial distribution of consumers across different facility with different sizes. However, such studies seldom take residential quarter as analysis unit, and analyze how single-type facility layout within the internal boundaries of a living circle influences the travel behavior of residents. Moreover, the observed phenomenon of “traveling farther despite nearer options” is often discussed only descriptively. There remains a lack of research that systematically extracts its spatial structural patterns or quantifies the mechanisms driving this behavior. The contribution of this study lies in being the first to quantitatively examine, within the 15-minute cycling living circle, the coupling relationship between the layout of a single facility type and long-distance trips occurring internally. The study identifies the spatial configurations of living-circle facility layouts associated with different travel distances and demonstrates that facility scale is the core driving force behind long-distance intra-circle travel.

6.1 Data, samples, and Variables

6.1.1 Data: multi-source Data

This section utilizes various data sources, including mobile phone signaling data, building and land use boundary data, public review data from platforms like Dianping, residential quarter boundaries, and living circle boundaries, to statistically analyze the facility layout and travel characteristics of each residential sample within the living circle.

The travel data is derived from mobile phone signaling data, with the identification method based on the building land use boundary clipping technique (as shown in the diagram Figure 6.3). The land use boundary data comes from the government’s third national land survey, and adjustments are made according to government disaster data on building outlines. The calculation of the building area for supermarkets and vegetable markets is based on the building area data from the government disaster data. There are 41 supermarkets and 51 vegetable markets in total. The city-wide travel data for supermarkets amounts to 90,696 entries, while the data for vegetable markets is 12,334 entries. Within the 15-minute cycling living circles, the travel data for supermarkets is 46,792 entries, and for vegetable markets, it is 3,283 entries.

After merging the OD flow clusters for trips from the same residential quarter to the

same facility (as illustrated), the data results in 8,453 OD flow clusters for supermarkets across the city, 2,590 OD flow clusters for vegetable markets, 2,927 OD flow clusters for supermarkets within the 15-minute cycling living circle, and 757 OD flow clusters for vegetable markets within the same living circle.

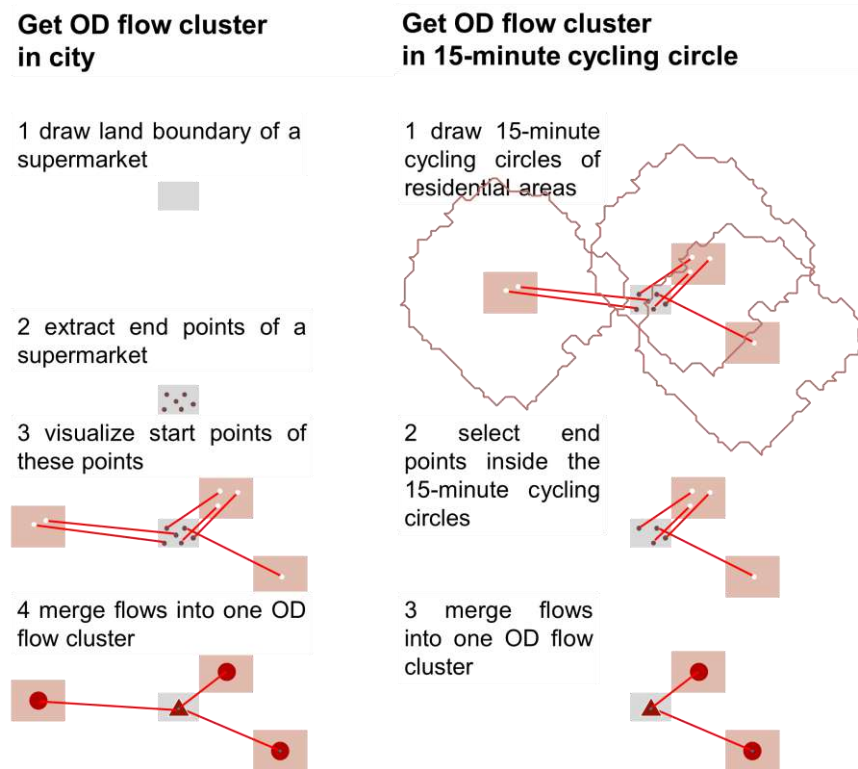


Figure 6.3 Generation of OD flow clusters from trip destinations

(Left: City-wide, Right: 15-minute Cycling Living Circle Example)

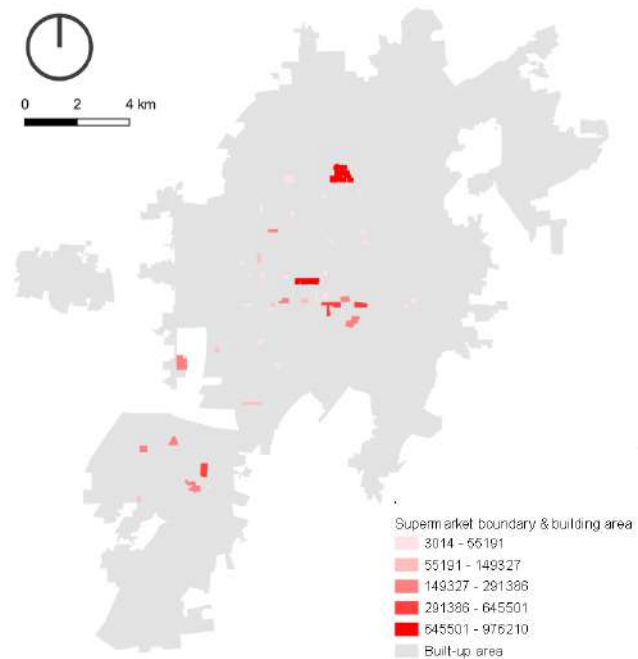
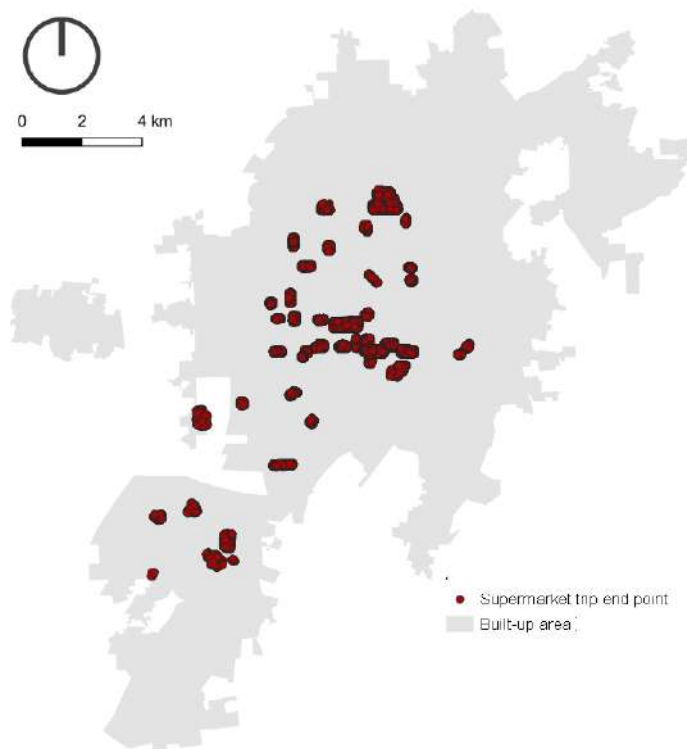


Figure 6.4 Supermarket land use boundary and building area



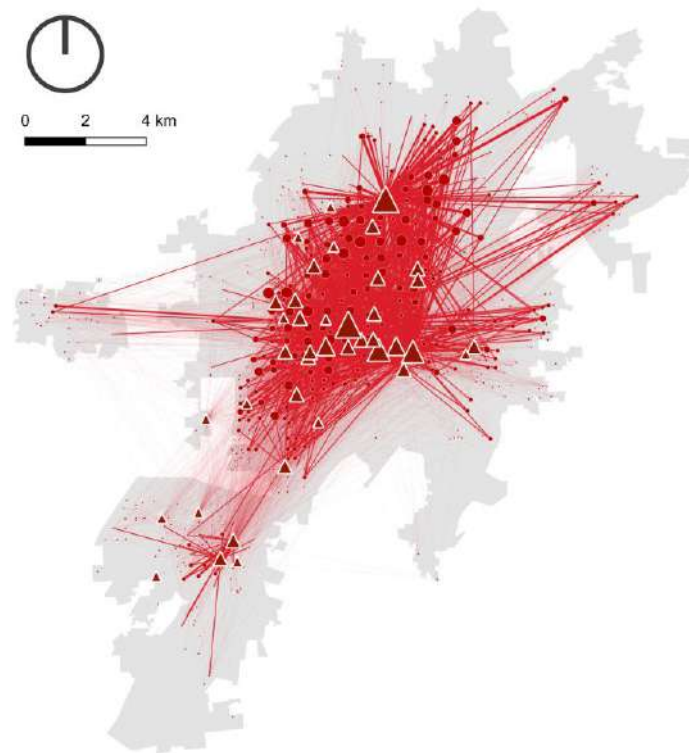
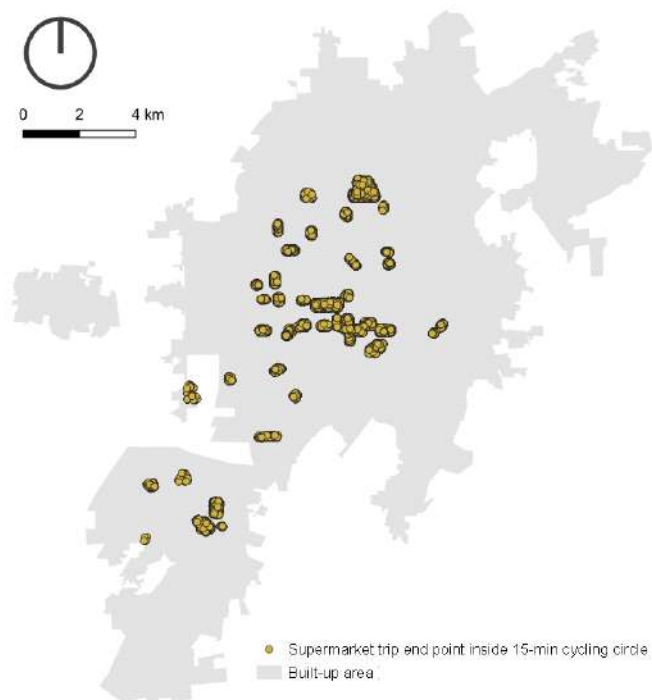


Figure 6.5 City-wide supermarket trip destinations and residential quarter-supermarket OD flow clusters



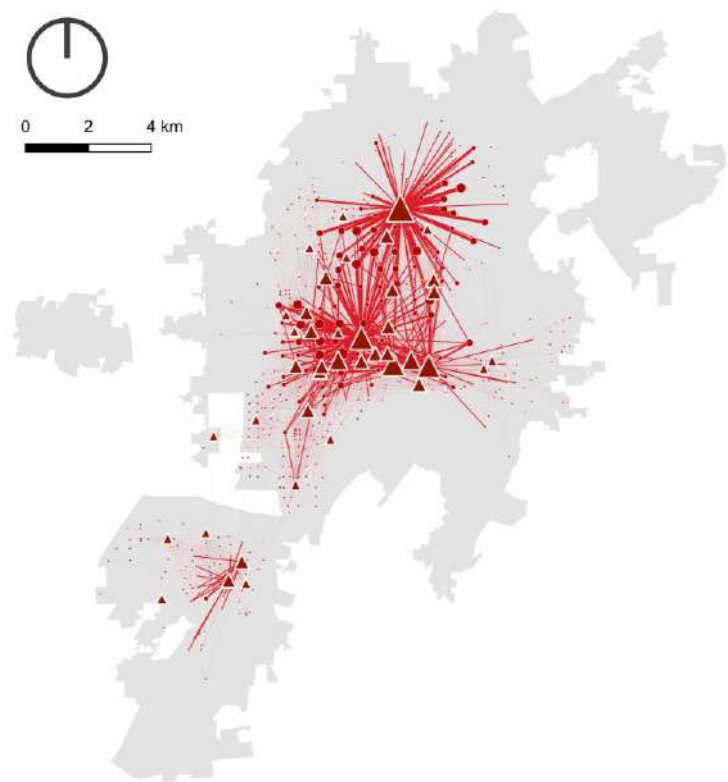


Figure 6.6 Supermarket trip destinations and residential quarter-supermarket OD flow clusters within the 15-minute living circle

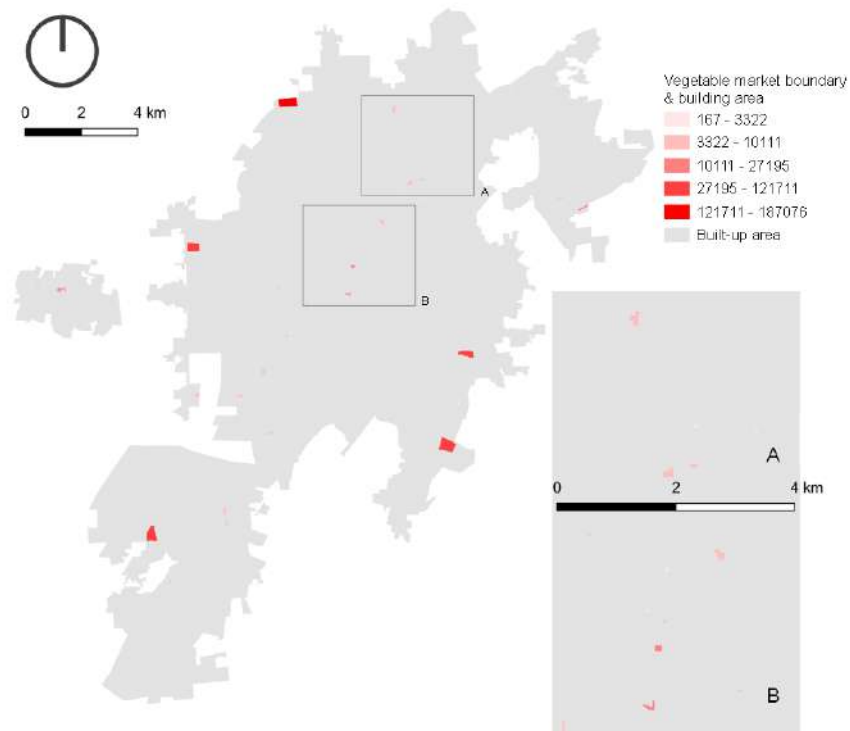


Figure 6.7 Vegetable market land use boundary

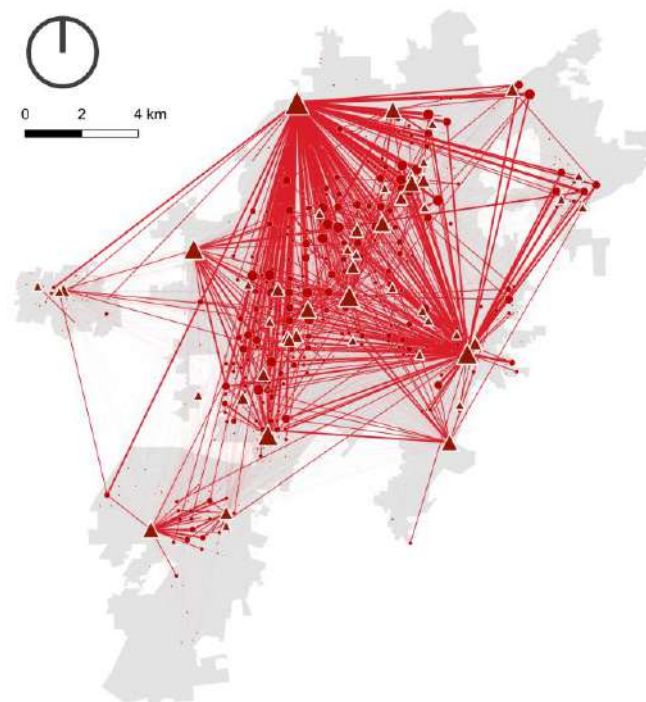
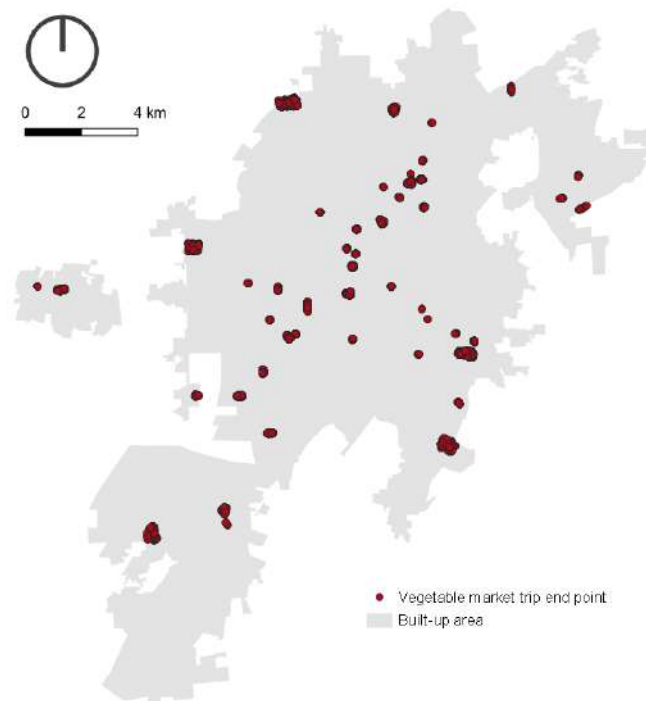


Figure 6.8 Destination of trips to the city's vegetable markets and OD flow clusters between residential quarters and vegetable markets

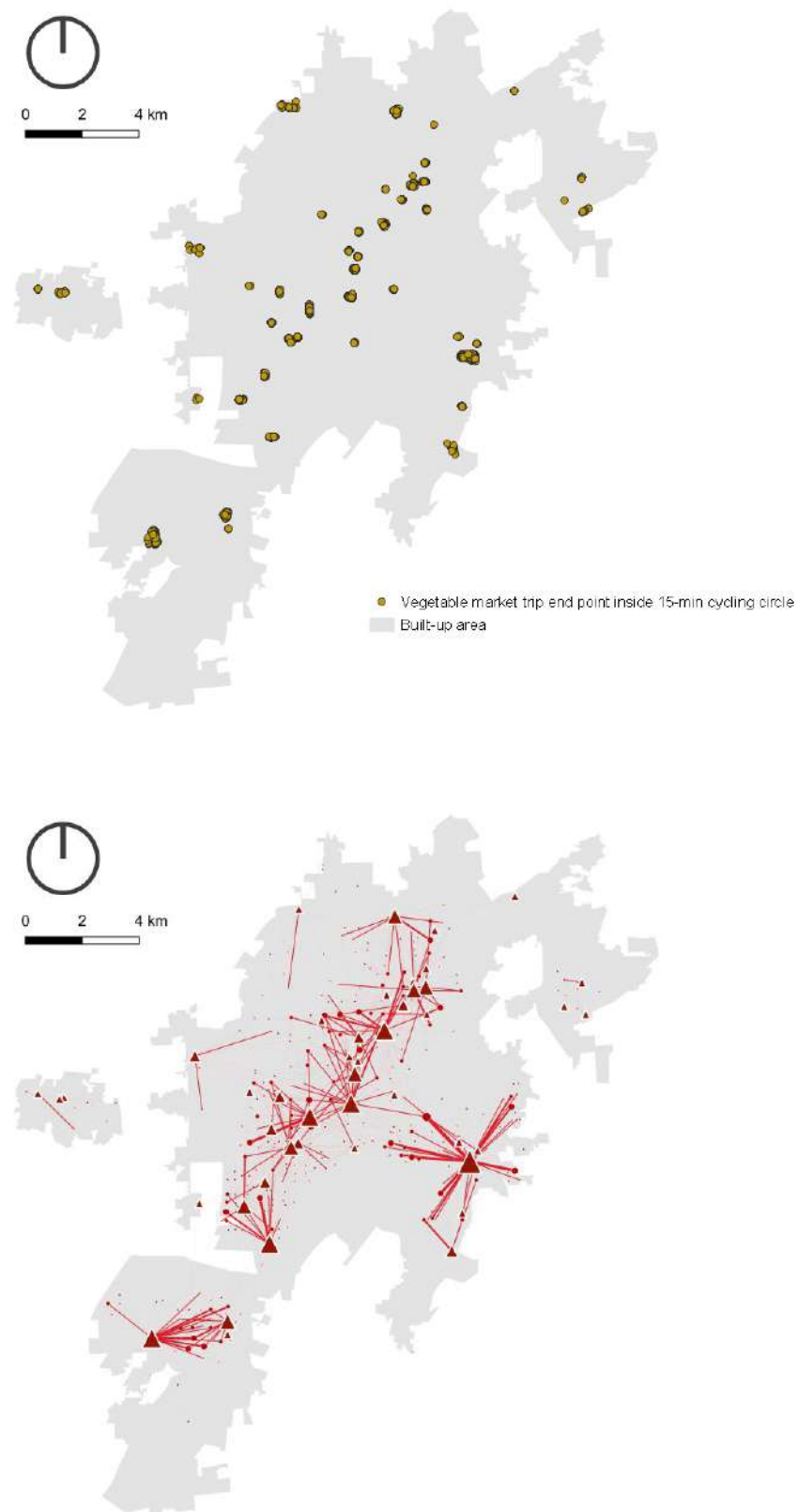


Figure 6.9 Destination of vegetable market travel within 15 minute living circle and OD flow cluster between residential quarter and vegetable market

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Table 6.1 Travel data and OD flow cluster statistics

	Supermarkets	Vegetable markets
Quantity	41	51
City-wide trip count	90696	12334
Number of residential- facility OD flow clusters city-wide	8453	2590
Trip count within 15-minute cycling circles	46792	3283
Number of residential- facility OD flow clusters within 15-minute cycling circles	2927	757
Number of residential quarters at the origin points of trips within the 15-minute cycling circle	533	357

Taking supermarket trips in residential quarters as an example, preprocessing and flow cluster statistics were conducted for each residential quarter sample to lay the foundation for the subsequent dependent and independent variable statistics. Calculate the number of trips and travel choice probability for each flow cluster (as shown in the table). In this study, each OD flow cluster flow direction record consists of the following fields:

shuziID: The unique identifier for the residential quarter (origin).

- **shchID**: The unique identifier for the facility (e.g., supermarket or vegetable market).
- **szIDscID**: The combined key of shuziID and shchID for the specific "residential quarter → facility" OD flow.
- **nmbtraszsc**: The total number of trips made from the residential quarter to the specific facility (shchID).
- **nmbtrasz**: The total number of trips made from the residential quarter to all facilities.
- **propsc**: The proportion of trips made to a specific facility out of all trips from that residential quarter, reflecting the probability of choosing that facility.
- **fjzzongmj_**: The total area of the facility, which is used to assess the attraction of the facility.
- **ODdistan**: The Euclidean distance from the residential quarter to the facility.

- **nmbOD**: The number of OD flow clusters, indicating the number of facilities visited by that residential quarter.

Table 6.2 Calculation of trip numbers and trip selection probability for each OD flow cluster

shc hl D	shu zil D	szID scID	shch ID_x	shch ID_y	shuzi ID_x	shuzi ID_y	nmbtr aszsc	nmb trasz	pro psc	fjzzo ngmj	ODd istan	nm bOD
18	163	1638	118.	39.5	118.1	39.5	3	4	0.7	2093	1142	2
	8	_18	1051	6232	061	7255			5	67.4		
8	163	1638	118.	39.5	118.1	39.5	1	4	0.2	1015	2814	2
	8	_8	1304	8959	061	7255			5	66.6		

Taking the two OD flow clusters from residential quarter 1638 to supermarkets 18 and 8 as an example, this residential quarter has a total of four trips to supermarkets, three trips to supermarket 18, and one trip to supermarket 8, with travel distances of 1142 meters and 2814 meters respectively. This residential quarter has a higher probability of traveling to nearby and large supermarkets, with a probability of 0.75, reflecting that residents' travel to supermarkets is essentially a choice made after measuring their attractiveness and travel costs (as shown in Figure 6.10).

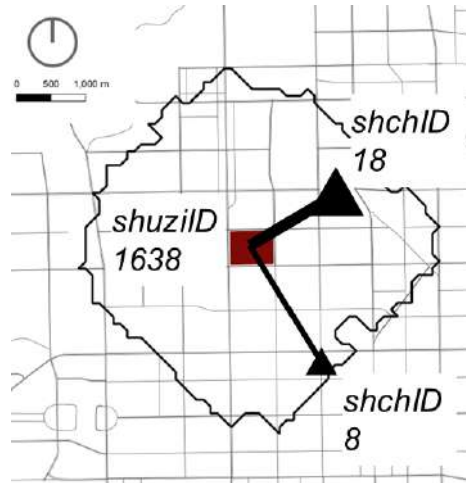


Figure 6.10 Schematic diagram of travel from residential quarter 1638 to supermarkets 18 and 8

6.1.2 Samples: 890 two-type 15-minute cycling living circles

The sample for the supermarket study includes data from 533 residential quarters and their corresponding travel data, while the sample for the vegetable market study includes data from 357 residential quarters and their corresponding travel data. For further details, please refer to section 3.4.3 "Data."

The definitions of supermarkets and vegetable markets are as follows:

- **Supermarkets:** According to the *Cihai Dictionary*, a supermarket is "a market composed of various shops gathered in one or several connected buildings." In this paper, supermarkets refer to integrated commercial spaces consisting of multiple retail shops, dining services, and leisure entertainment facilities, offering a one-stop shopping, dining, and entertainment experience. They typically feature large department stores or supermarkets as anchor tenants and include basic infrastructure such as parking lots and public passages. Examples include Tangshan Department Store, Bafang Shopping Plaza, and Wanda Plaza.
- **Vegetable Markets:** According to the *Cihai Dictionary*, a vegetable market is "a place where vegetables, meat, and other foodstuffs are sold." In this paper, vegetable markets refer to fixed locations in urban or rural areas where free trade of agricultural products occurs, including vegetables, fruits, seafood, poultry, meat products, grains, legumes, cooked food, seasonings, and local specialties. These markets primarily operate as retail businesses and include locations such as the Standardized Vegetable Market in Lubei District, Tangshan, Deyuanli Market, and Hehuakeng Small Wholesale Market.

Type	Supermarkets	Vegetable markets
Name	Tangshan Department Store	Tangshan Lubei District Standardized Food Market (Jibeilou Branch)
Address	No. 125 Xinhua East Road, Lubei District, Tangshan City	No. 23, Airport Road
Three- dimensional perspective		



Figure 6.11 Case studies of supermarkets and vegetable markets

The reasons for selecting supermarkets and vegetable markets are as follows:

1. **Impact on Green Travel:** Supermarkets and vegetable markets have a significant influence on green travel. Among all facility types, vegetable markets rank first, while supermarkets rank third in terms of their impact. The supermarkets used in this study are a further selection of comprehensive malls from those discussed earlier. These malls have a high overlap with the central area and the nmbike10cc indicator, where "third" refers to the ranking based on the nmbike10cc indicator.
2. **Role as a Living Center:** Both supermarkets and vegetable markets fit the role of a "living center" within a 15-minute living circle. The theory of living circles in Japan was initially proposed based on research and empirical analysis conducted in commercial districts, with Ishikawa Nobuyoshi's work being a key example.
3. **Planning Practice Representation:** In the "Tangshan Quarter-Hour Convenient Living Circle Plan," supermarkets and vegetable markets are representative facilities selected for key research and planning in the study of living circle layouts.

6.1.3 Dependent variable: average travel distance to facilities in a living circle

Based on 533 district samples, the dependent variable is the average travel distance to supermarkets within a 15-minute cycling living circle. The average travel distance ranges from 559 meters to 3760 meters, with significant differences. The overall sample mean is 2009 meters. Dark black areas are found in peripheral or edge districts, forming ring-shaped or isolated patches. This indicates that these districts lack supermarket

facilities within their living circles or that the existing malls are unable to meet shopping demands, forcing residents to travel longer distances to reach their target mall. These districts are often "hollow" or "near-rural porous" living circles. Light-colored areas are mainly located in the central region, commercial cluster zones, or major commercial corridors. This shows that these districts have a more reasonable supermarket layout, higher supermarket density, and greater shopping convenience, typically representing "multi-core" or "near-core mixed" living circles.

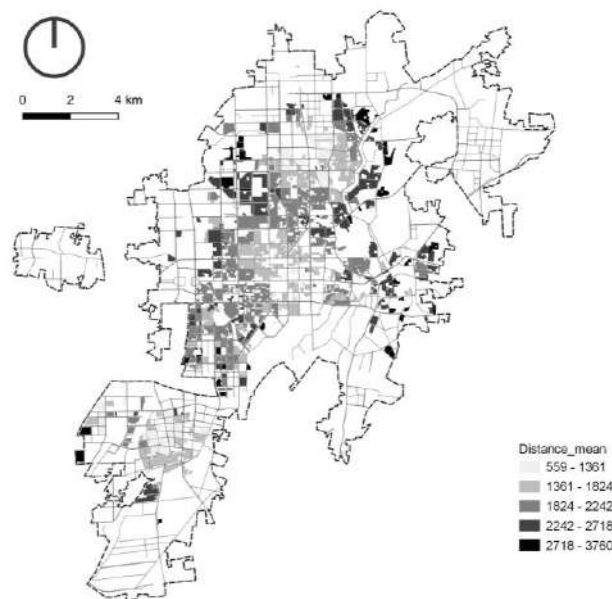


Figure 6.12 Average travel distance to supermarkets in a 15-minute cycling living circle for districts

The histogram indicates that the travel distances to malls follow a normal distribution, with most values falling between 1939 meters and 2399 meters.

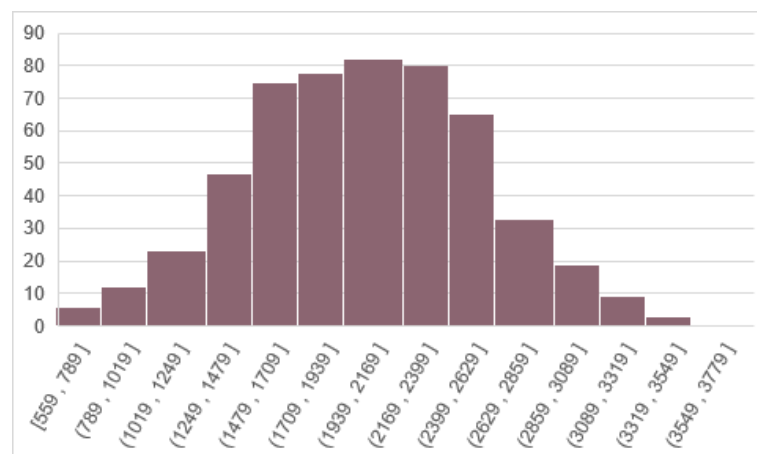


Figure 6.13 Histogram of average travel distance to supermarkets in a 15-minute cycling living circle

(Sample: 533, Mean: 2009 meters)

The average travel distance to vegetable markets within a 15-minute cycling living circle for districts shows a spatial gradient that increases from the center to the edges and then decreases. The black areas (2141–3769 meters) are mostly concentrated in the northern part of the city, reflecting the insufficient availability of vegetable markets in these districts or the inability of existing markets to meet residents' shopping needs. Residents must travel longer distances, either toward the city center or outwards, to satisfy daily purchasing needs. These districts are often "hollow" living circles. The lighter-colored areas (268–1663 meters) are predominantly located in the central, northeastern, and southwestern parts of the city, indicating that these districts have a higher density of vegetable markets and greater travel convenience.

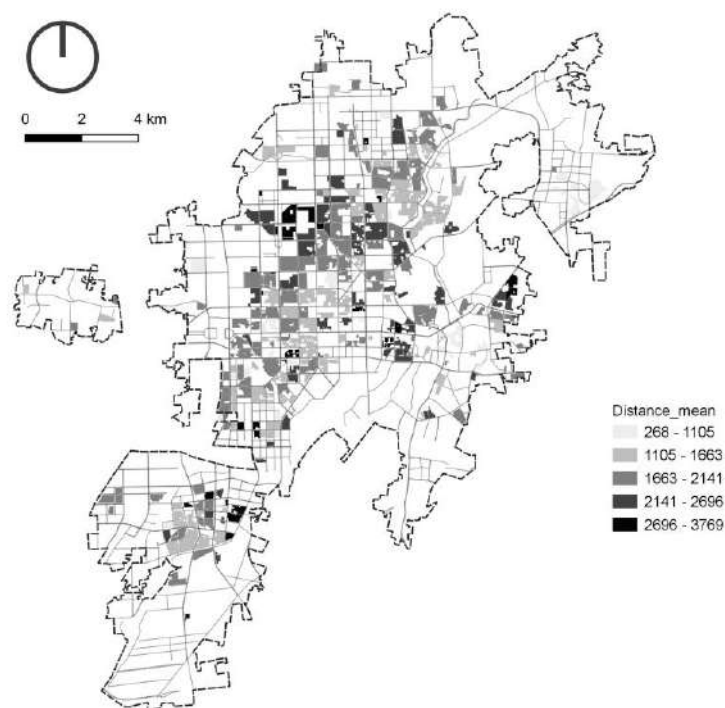


Figure 6.14 Average travel distance to vegetable markets in a 15-minute cycling living circle for districts

The histogram shows that travel distances to vegetable markets follow a normal distribution, with most values ranging between 1468 meters and 2068 meters.

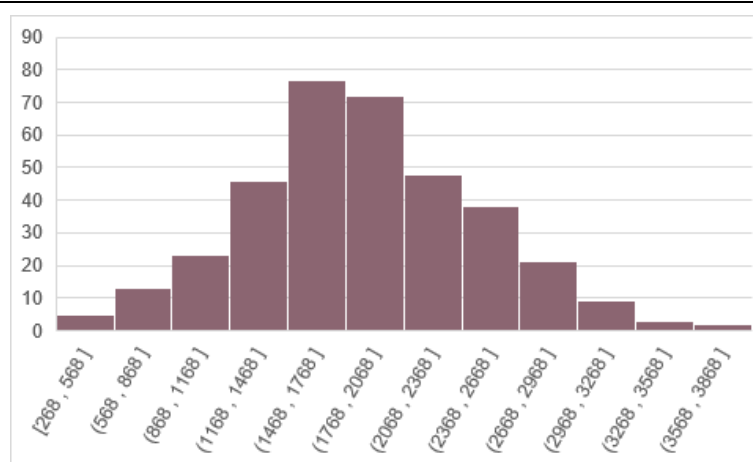


Figure 6.15 Histogram of average travel distance to vegetable markets in a 15-minute cycling living circle

(Sample: 357, Mean: 1855 meters)

6.1.4 Independent variables: 30 indicators of single facility layout in a living circle

This section selects independent variables across the following five dimensions: Scale, Accessibility, Attitude, Density, and Road Condition.

6.1.4.1 Reason for variables selection: scale as a representative variable for supply characteristics

In the subsequent description of facility layout, it is not feasible to include all facility characteristics. For instance, the "spatial design" of the nearest supermarket within a residential quarter's 15-minute circle and the distance to the best supermarket in terms of spatial design. Therefore, this study chooses scale (building area) as the facility characteristic in the description of the facility layout, such as the "scale" of the nearest facility within the residential quarter. More details of Section 6.1.4.1 please refer to the APPENDIX D. There are two main reasons for this choice:

Reason 1: Scale is a national standard for planning. In the "Urban Residential quarter Planning and Design Standards 2018," Appendix C of the standards for the planning and construction of supporting facilities in residential quarters uses scale (building area, square meters) as the basis for the planning of various facilities.

Reason 2: Scale is widely used in interaction models. In spatial interaction models such as the Huff model, scale is considered to represent the attraction of a facility to

consumers, as larger facilities are more likely to offer the products consumers need to buy.

The study verifies that scale (building area) can be an important feature influencing the "near vs. far" decision, affecting destination choice and leading to longer travel distances, through impact feature determination, correlation, visualization, and modeling.

(1) Scale as a Comprehensive Representative of Facility Characteristics Influencing the "Near vs. Far" Selection in Residential quarters

The study first evaluates the "near vs. far" travel behavior in residential quarters. Based on the OD flow cluster data from Section 7.2.2, it was found that, on average, residential quarters within the 15-minute cycling living circle visit 5.49 supermarkets and 2.12 vegetable markets. This suggests that most residents tend to visit multiple destinations. For this purpose, the study defines three categories: the nearest flow cluster, the non-nearest most frequent flow cluster, and the non-nearest all flow clusters, and evaluates these categories using five dimensions: sample proportion, distance difference, and travel frequency differences. The detailed description of the evaluation indicators and individual residential quarter evaluation results can be found in the appendix. The results show that the "near vs. far" behavior is most significant for supermarkets: 75.98% of residential quarters (405 out of 533 samples) have multiple supermarket destinations, with the average travel distance of the non-nearest most frequent flow clusters being 1029.21 meters longer than that of the nearest flow clusters. The number of trips to these destinations was 17,588 more, indicating a clear preference for farther destinations. For vegetable markets, 46.22% of residential quarters exhibit the "near vs. far" phenomenon, with a distance difference of approximately 920 meters and a frequency difference of 424 trips. This preference is significantly weaker than that for supermarkets, showing better proximity.

Table 6.3 Evaluation of bypassing behavior for supermarkets based on all residential quarter samples

Supermarkets	Total sample scale (units)	Bypassing sample scale (units)	Proportion of samples with multiple flow clusters (none)	Maximum distance difference to nearest (meters)	Total distance difference to nearest (meters)	Maximum frequency difference to nearest (times)	Total frequency difference to nearest (times)
cluster1-4	533	405	75.98%	1029.21	1074.33	17588	1077.17

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Table 6.4 Evaluation of bypassing behavior for vegetable market based on all residential quarter samples

Supermarkets	Total sample scale (units)	Bypassing sample scale (units)	Proportion of samples with multiple flow clusters (none)	Maximum distance difference to nearest (meters)	Total distance difference to nearest (meters)	Maximum frequency difference to nearest (times)	Total frequency difference to nearest (times)
cluster1-4	357	165	46.22%	920.45	942.36	424	11.23

To further explore the reasons, the study combines the 2927 residential quarter—supermarket and 757 residential quarter—vegetable market flow clusters with data from online review platforms (e.g., Dianping). The study compares 12 features (construction year, per capita consumption, environment, scale grade, variety, etc.) of the nearest and most frequent non-nearest flow clusters. Using the weighted feature difference ΔQ based on the number of trips from residential quarters, the study groups residential quarter samples with flow clusters ≥ 2 and eliminates cases where the number of trips to the nearest flow cluster significantly exceeds that of the distant flow clusters to avoid interference. The feature quality was assessed using a large language model with manual instructions, and the values were assigned as 1, 0, or -1. Detailed methods, feature meanings, and quality results of supermarkets and vegetable markets can be found in the appendix.

The results show that the "near vs. far" behavior for supermarkets is primarily driven by factors such as spatial design, variety, scale grade, and environment. Accessibility, extended functions, and auxiliary facilities are secondary, while service quality has little effect. For vegetable markets, scale grade, variety, and extended functions dominate, with other factors having a weaker influence, and environmental factors are not significant. Therefore, scale and variety play a decisive role in residential quarters' preferences for distant destinations.

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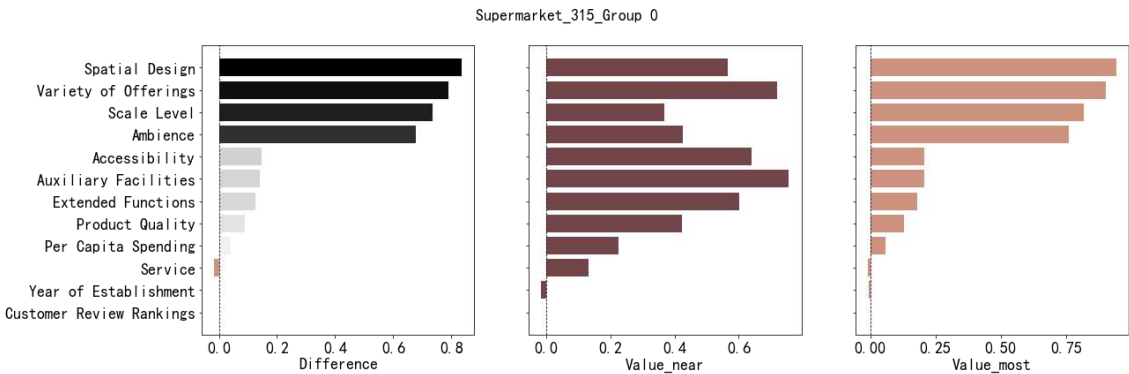


Figure 6.16 Reasons for choosing a distant supermarket over a nearby one

(The left figure shows the reasons that the difference in quality scores between the non-nearest supermarket with the most clusters and the nearest supermarket clusters; the middle figure shows the sum of quality scores of the nearest supermarket clusters; the right figure shows the sum of quality scores of the non-nearest supermarket with the most clusters. Same as the vegetable market)

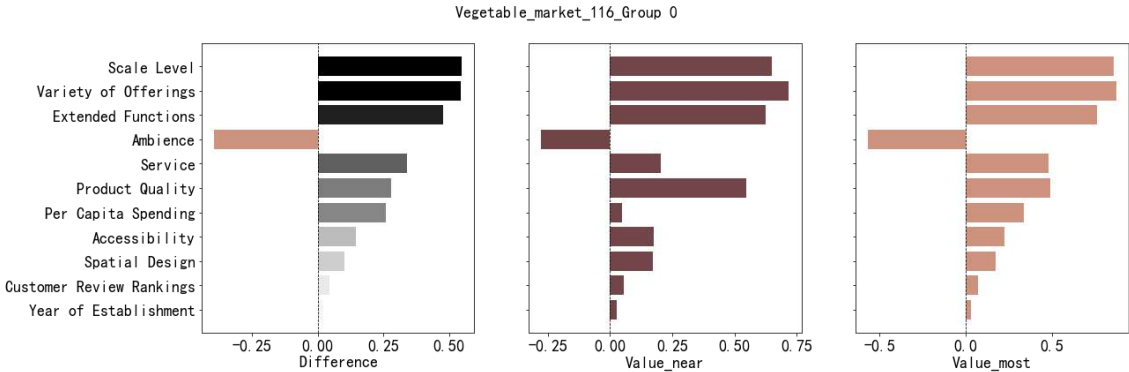


Figure 6.17 Reasons for choosing a distant vegetable market over a nearby one. The left figure shows the reason

The correlation test further confirms that scale can represent the overall characteristics of facilities. Pearson and Spearman correlation coefficients show that the scale grade of supermarkets is highly correlated with spatial design, variety, and environment (correlation coefficients of 0.34-0.48), while vegetable market scale is more highly correlated with variety and extended functions (0.54-0.74). This indicates that scale not only explains the "near vs. far" behavior but also serves as a representative variable for facility quality and attractiveness, making it useful for subsequent facility layout analysis.

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Table 6.5 High correlation between supermarket scale and spatial design, variety, ambience

Correlation between Scale	Pearson	Spearman
Spatial Design	0.477223	0.473952
Ambience	0.375384	0.36116
Variety of Offerings	0.342646	0.374269

Table 6.6 High correlation between vegetable market scale and variety, extended functions

Correlation between Scale	Pearson	Spearman
Variety of Offerings	0.690496578	0.739249324
Extended Functions	0.540489586	0.591312396

(2) Differential Impact of Facility scale on Travel Attraction Distance

The study further investigates the significant role of facility scale in destination choice and travel distance by classifying facilities based on size. Using building area (calculated based on the actual building area for both supermarkets and vegetable markets), the facilities are divided into high, medium, and low categories using the natural breaks method, and residential quarter—facility flow cluster distribution maps are created.

The results show that, for both supermarkets and vegetable markets (Figure 6.18, Figure 6.19), all facility levels can cover all residential quarters in the city, exhibiting an interlocking central-place distribution pattern. High-level facilities have a larger number of flow clusters and a broader service radius, followed by medium-level facilities, with low-level facilities having the weakest effect. Flow cluster distribution maps of typical cases further indicate that as the facility level increases, its service radius and coverage intensity also increase.

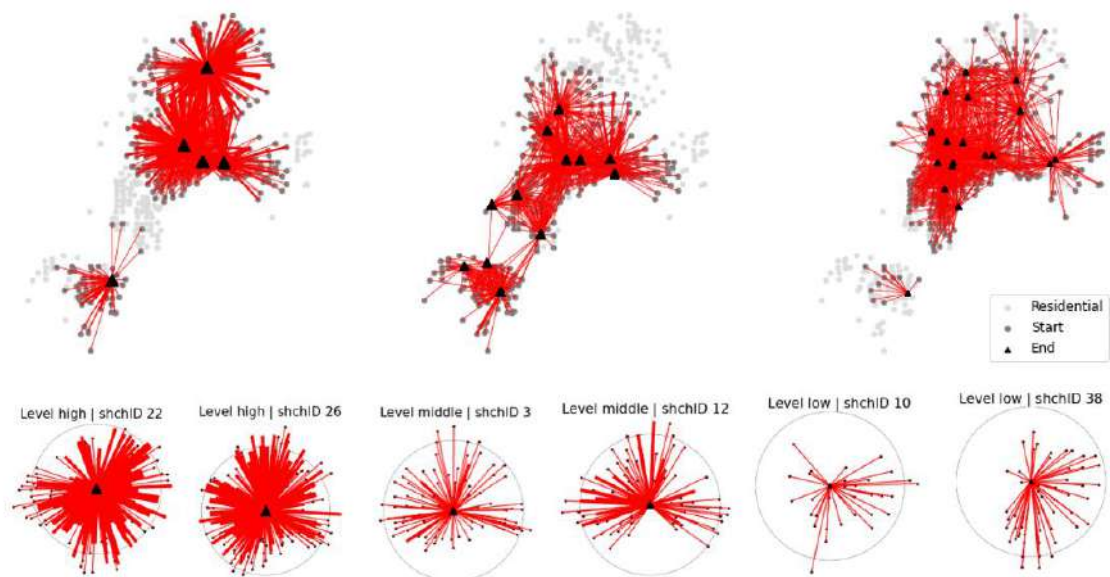


Figure 6.18 Residential quarter-supermarket flow cluster diagram within a 15 minute living circle based on supermarket classification

(light colored dots represent all residential quarters, dark gray dots represent the starting residential quarters of the flow clusters, black triangles represent the ending malls of the flow clusters, and the size of triangles represents the level of the malls; ShchID is supermarket code)

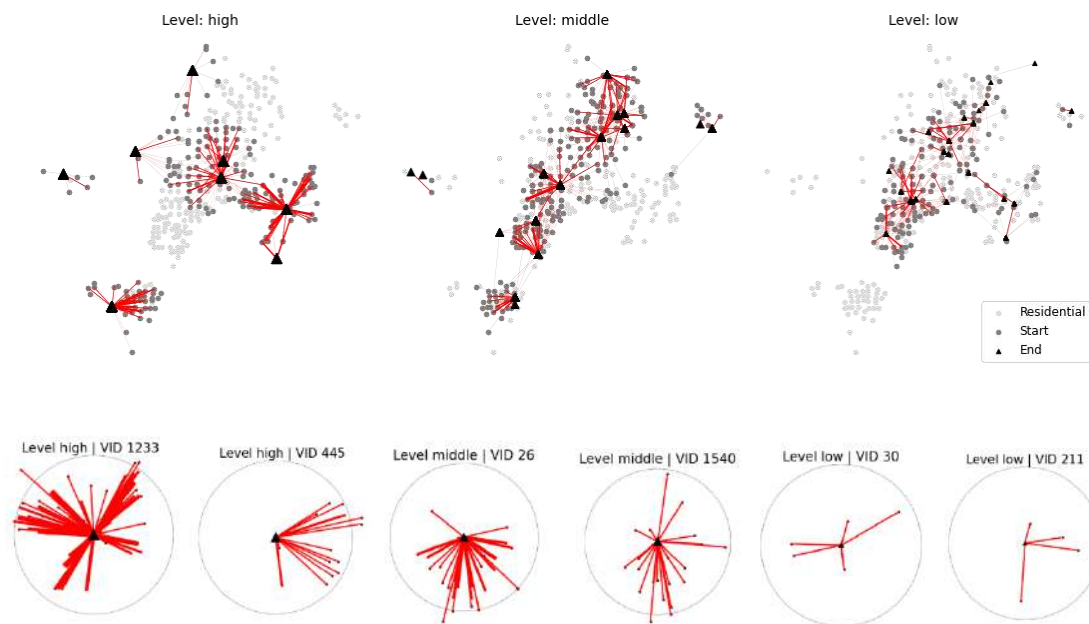


Figure 6.19 Residential quarter-vegetable market flow cluster diagram within a 15 minute living circle based on vegetable market grading (same as supermarket; VID is vegetable market code)

Statistical analysis also confirms this trend: the average travel distance and maximum travel distance of high-level supermarkets and vegetable markets are significantly higher than those of medium and low-level ones, indicating that residents are more inclined to travel long distances for large-scale facilities, which have stronger appeal in their living circles.

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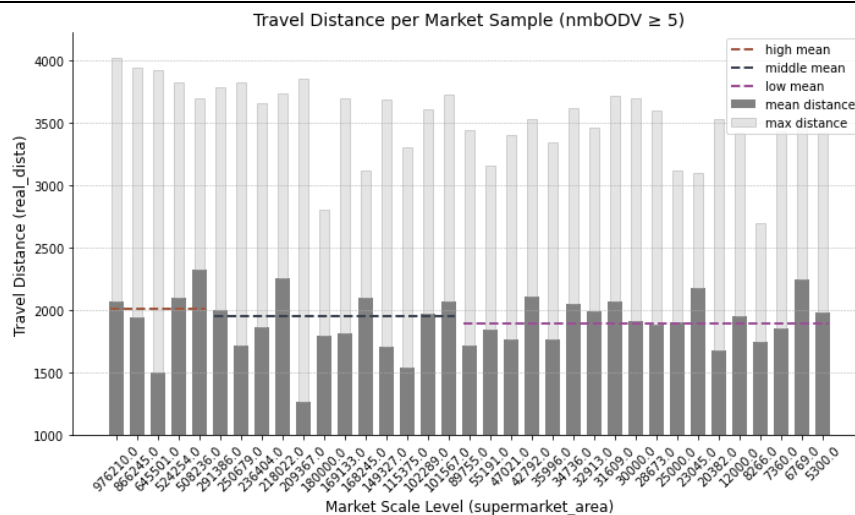


Figure 6.20 The higher the supermarket level, the longer maximum and average travel distances

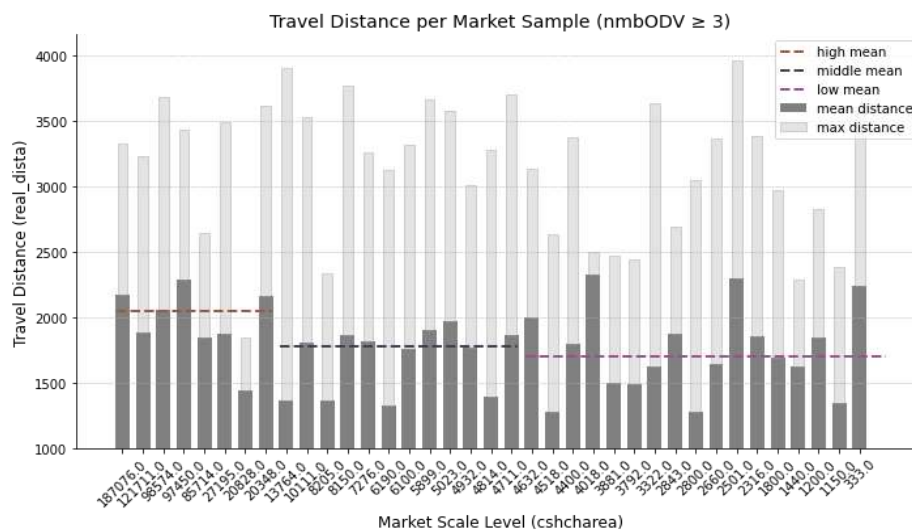


Figure 6.21 The higher the level of the vegetable market, the longer the maximum and average travel distances

For malls, large-scale malls (with a floor area exceeding 500,000 square meters, with an average of approximately 704,000 square meters) have a weighted average travel distance of 2,011 meters, and their maximum travel distance is close to 3,786 meters. This is significantly higher than the weighted average travel distance of medium-sized malls (1,955 meters) and the maximum distance (3,562 meters), as well as smaller malls, which have a weighted average distance of 1,893 meters and a maximum of 3,406 meters.

The same pattern is observed in vegetable markets: large vegetable markets (with a floor area exceeding 20,000 square meters, with an average of 82,400 square meters) have an average travel distance of 2,046 meters and a maximum distance of 2,955 meters.

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Medium-sized vegetable markets have an average travel distance of around 1,776 meters and a maximum of 2,614 meters, while small vegetable markets show average and maximum distances of 1,700 meters and 2,773 meters, respectively.

Large-scale facilities significantly influence residents' travel behaviors, as evidenced by the fact that even within a 15-minute living circle, residents tend to travel longer distances for higher-level malls or vegetable markets ("choosing to travel farther"). This pattern confirms the positive correlation between facility level and service radius, which aligns with the central place theory's expectation that higher-level facilities have a larger service range. It also suggests that facility scale is one of the key factors in explaining residents' long-distance travel behaviors.

Table 6.7 Statistical values showing longer maximum and average trip distances for higher-level supermarkets

Level	Number of malls	Mall scale range (min, max) (mean)	weighted_avg_distance weighted average travel distance (m)	weighted_max_distance weighted maximum travel distance (m)
high	5	(508236, 976210) (704089)	2011.096	3786.364
middle	12	(101567, 291386) (182650)	1954.551	3561.542
low	18	(5300, 89755) (29823)	1893.117	3405.673

Table 6.8 Statistical values showing longer maximum and average trip distances for higher-level vegetable markets

Level	Number of vegetable markets	Vegetable market scale range (min, max) (mean)	weighted_avg_distance weighted average travel distance (m)	weighted_max_distance weighted maximum travel distance (m)
high	8	(20348, 187076) (82362)	2046.019	2954.967
middle	16	(4711, 14767) (7338)	1775.572	2613.543
low	22	(333, 4632) (2676)	1699.653	2772.935

(3) Excellent Fitting Performance of the Huff Model Based on Facility scale for Travel Distribution

This study utilizes the Huff model based on citywide and 15-minute cycling zone travel data to verify the effectiveness of facility scale (building area) in destination choice, while also fitting the distance sensitivity coefficient (λ) and scale preference coefficient (γ). The introduction of dual-scale parameters is necessary because residents' sensitivity to distance and facility scale is context-dependent. Solely using 15-minute cycling zone data may underestimate the impact of cross-zone travel or facility level differences. Thus, the citywide sample better captures overall attitudes.

Methodology:

Firstly, a global fitting strategy is employed to determine the optimal λ and γ , with the criterion being the minimum SSE or maximum R^2 . This approach avoids biases due to uneven sample distribution, providing a more accurate reflection of the overall model compared to averaging by individual residential quarters^{[163][164][165]}. In contrast to traditional Huff models, which only fit distance decay, this study also incorporates scale preference and uses Euclidean distance in travel costs. The two corrected forms are exponential and power functions:

$$\hat{P}_{ij} = \frac{(S_j)^\gamma \exp(-\lambda T_{ij})}{\sum_k (S_k)^\gamma \exp(-\lambda T_{ik})} \quad (6-1)$$

$$\hat{P}_{ij} = \frac{(S_j)^\gamma (T_{ij})^{-\lambda}}{\sum_k (S_k)^\gamma (T_{ik})^{-\lambda}} \quad (6-2)$$

$$\sum_{j=1}^n P_{ij} = 1 \quad (6-3)$$

In these formulas, $\hat{P}_{ij}$ is the predicted probability of residential quarter i choosing supermarket j ; S_j is the size (building area) of supermarket j , γ is the scale coefficient representing the residential quarter's preference for supermarket size; T_{ij} is the Euclidean distance between residential quarter i and supermarket j ; λ is the distance decay coefficient representing the sensitivity to travel distance to the mall; and k is the total number of malls.

To select the optimal parameters, the sum of squared errors (SSE) is used as a

criterion:

$$SSE(\lambda, \gamma) = \sum_i \sum_j (\hat{P}_{ij}(\lambda, \gamma) - P_{ij})^2 \quad (6-4)$$

Where i represents the residential quarter, and j represents the supermarket that the residential quarter reaches. For each specific residential quarter i , the sum of the squared differences between the predicted probabilities and actual probabilities for all malls visited is computed. The total SSE is then calculated by summing across all residential quarters. Further details of the method can be found in the appendix.

Modeling based on global fitting, both the supermarket and vegetable market travel models show good fitting performance, with R^2 values above 0.58, validating the effectiveness of facility scale (building area) in explaining travel distribution. The exponential function provides a better fit than the power function. For malls, the R^2 is 0.7005, and for vegetable markets, the R^2 is 0.5911, with the SSE being lower for the exponential function. Thus, the exponential function is used for subsequent analysis (Figure 6.22, Figure 6.23).

Optimal Parameters Comparison: The optimal distance decay coefficient λ for malls (0.99) is significantly higher than for vegetable markets (0.53), indicating that residents are more sensitive to distance in supermarket travel. The scale preference coefficient γ is also higher for malls (0.66) than for vegetable markets (0.42), suggesting that supermarket attractiveness is more dependent on size, and residents are more likely to select larger-scale malls, even for distant destinations. In contrast, vegetable markets show lower sensitivity to both size and distance. Overall, supermarket travel exhibits stronger scale preference and distance sensitivity, providing a mechanistic explanation for the "choosing farther over closer" behavior.

Table 6.9 Optimal parameters and corresponding SSE and R2

	Function form	Optimal global λ	Optimal global γ	Minimum SSE	R2
Supermarkets	Exponential function	0.99	0.66	27.60	0.7005
	Power function	0.23	0.64	28.61	0.6892
Vegetable markets	Exponential function	0.53	0.42	6.91	0.5911
	Power function	0.05	0.42	6.99	0.5862

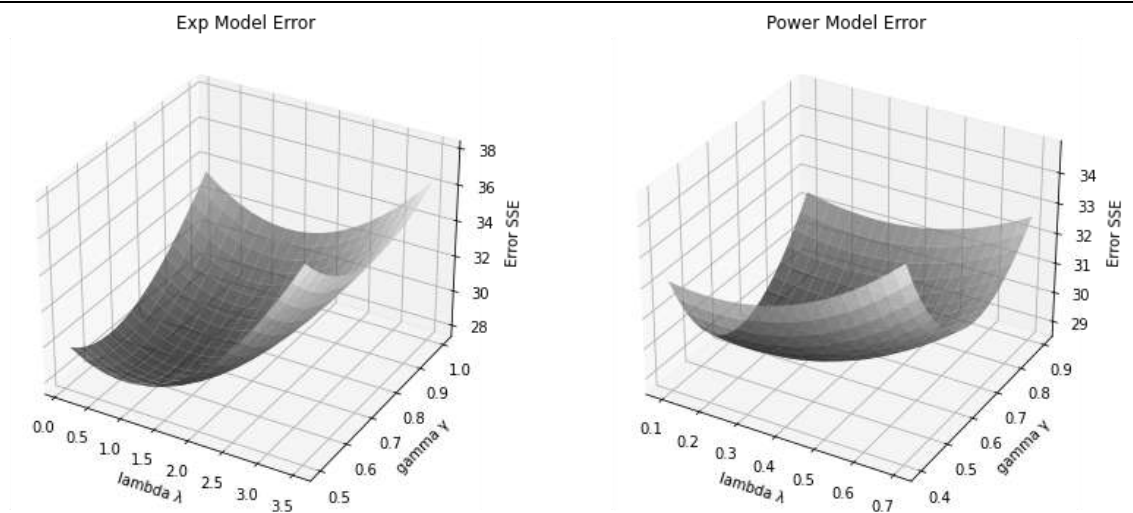


Figure 6.22 Supermarket travel distribution and SSE changes for both function forms the figure shows how the SSE changes for both the exponential and power functions, indicating the best values of λ and γ that minimize SSE.

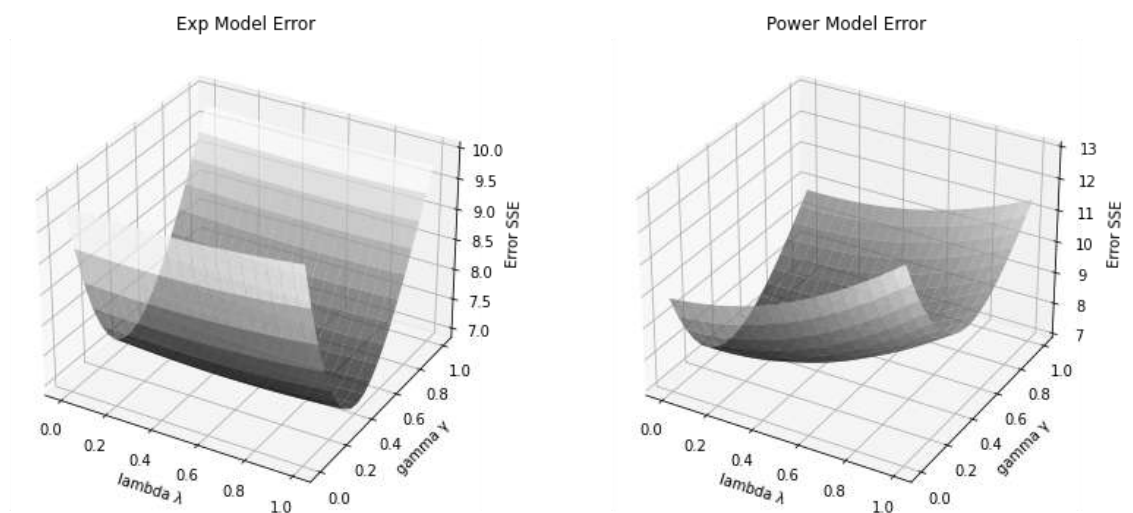


Figure 6.23 Vegetable market travel distribution and SSE changes for both function forms similar to the supermarket travel distribution, this figure shows the changes in SSE and identifies the best parameters for the vegetable market.

Further fitting by residential quarter shows significant heterogeneity in parameters, with significant differences in λ and γ between different residential quarters, reflecting the influence of spatial location and facility conditions on residents' travel behavior. The two parameters of each residential quarter within the 15 minute cycling living circle are shown in the table. This set of parameters is calculated based on the travel data and selection probability within the 15 minute living circle. The sensitivity coefficients λ and γ for city wide travel are calculated based on city wide travel data and selection probability. Please refer to the appendix for the detailed results.

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Table 6.10 Two parameters and corresponding SSE for each residential quarter within
supermarket 15-minute cycling living circles

(showing first 10 rows only due to data length)

shuziID		bstlmbike	bstgmbike	SSE
Residential code	quarter	Distance coefficient supermarket within cycling circle	decay λ for trips 15-minute	Scale coefficient supermarket 15-minute cycling circle
1011		0.1		0.871429
1026		0.7		1.055102
1132		1.1		0.357143
1133		0.3		0.210204
1136		6.9		0.614286
1142		2.7		0.797959
1172		8.9		1.128571
1173		0.1		0.761224
1176		2.3		1.495918
1191		3.7		0.577551

Table 6.11 Two optimal parameters and corresponding SSE for each residential quarter within
vegetable market 15-minute cycling living circles

(showing first 10 rows only due to data length)

shuziID		bstlmbike	bstgmbike	SSE
Residential code	quarter	Distance coefficient vegetable market within cycling circle	decay λ for trips 15-minute	Scale preference coefficient γ for vegetable market trips within 15-minute cycling circle
1026		0.1		0.136735
1176		0.5		0.1
1250		1.3		0.393878
1261		0.1		0.65102
1266		3.1		1.826531
1333		1.7		0.1
1451		7.1		0.1
1457		0.7		0.1
1460		0.1		1.9
1470		2.3		0.1

Based on the results, facility scale (building area) has been validated as a key factor influencing destination choice and travel distance. It serves as a core indicator of supply

characteristics. In the subsequent analysis, size-related variables (such as the size of the largest mall, *scale_lgst*, and the corresponding distance, *Oddis_lgst*, as well as the size of the nearest mall, *scale_nst*) will be used as fundamental explanatory variables for analyzing the average travel distance in the living circle.

6.1.4.2 Selection of variables: maximum facility scale and distance indicators

Based on the three-circle framework and six dimensions, the following independent variable indicators are selected (as shown in Table 6.12). Since the travel indicators for supermarkets and vegetable markets are almost identical, the description will focus on supermarkets as representatives. Moreover, the indicators primarily focus on the malls that are travel destinations, such as the number of malls in a 15-minute living circle rather than the total number of malls within the circle. This choice is made because the two values are closely related. Additionally, in previous sections, the facility layout's impact on green travel has already been analyzed, so further repetition would not be meaningful. Simplifying the complex layout characteristics allows for a more precise analysis of the spatial interaction between facilities and travel. In travel studies, it is common to focus only on the start and end points of OD flows, omitting other elements.

Table 6.12 Independent variables and corresponding dimensions and interaction dimensions

Note: R, W, C and T represents Residential quarter, 15-minute walking living circle, 15-minute cycling living circle and Control variable

Six interaction dimensions	Threes circles	Supermarket (S) and (or) vegetable market (V)	Index	Variable name	Unit
Attitude	R	S+V	Distance decay coefficient with city- reflects attitude preference	<i>bstlmdcity</i>	none
	R	S+V	Distance decay coefficient within 15-min cycling circle- reflects attitude preference	<i>bstlmdbike</i>	none
	R	S+V	Scale coefficient within city- reflects attitude preference	<i>bstgmcity</i>	none
	R	S+V	Scale coefficient within 15-min cycling circle- reflects attitude preference	<i>bstgmbike</i>	none
Density	C	S+V	Number of supermarkets visited within 15-minute cycling circle	<i>nmbOD</i>	number

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Scale	C	S+V	Number of trips to the supermarket within 15-minute cycling circle	nmbtrasz	number
	W	S+V	Number of supermarkets visited within 15-minute walking circle	nmbODw	number
	W	S+V	Number of trips to the supermarket within 15-minute walking circle	nmbtraszw	number
	C	S+V	The largest supermarket visited	scale_lgst	square meters
	C	S+V	The scale of the closest supermarket visited	scale_nst	square meters
	C	S+V	Average scale, the total scale of the supermarkets visited divided by the number of supermarkets visited	scale_ave	square meters
	C	S+V	The level of supermarket hinterland at the city level	n3mkt	level
Accessibility	C	V	Open time in a day of the nearest vegetable market	tmap_nst	hour
	C	V	Open time in a day of vegetable markets in 15-minute cycling circle	tmap_ave	hour
	C	S+V	Distance to the largest supermarket visited	Oddis_lgst	meter
	C	S+V	Distance to the nearest supermarket among visited	Oddis_nst	meter
	C	S+V	Satisfaction, the proportion of trips in 15 cycling circles to all trips	bktocity	ratio (0–1)
	W	V	Satisfaction, that is, the proportion of supermarket trips within a 15-minute walking circle to all trips	wktocity	ratio (0–1)
	W	S+V	Satisfaction, that is, the ratio of supermarket trips within a 15-minute walking circle to the number of trips within a 15-minute cycling circle	wktobk	ratio (0–1)
Road condition	W	S	Average travel distance	dismeanw	meter
	R	S	Distance from residential quarters to important commercial corridors	distcmwens	meter
	C	V	green travel degree of the nearest vegetable market OD	dengre_nst	travels per square kilometer
	C	V	non-green travel degree of the nearest vegetable market OD	denngr_nst	travels per square kilometer
	T	S+V	Residential population density	czzrk_smyx	People per square kilometer
—	T	S+V	Age of residence	agemean	age
	T	S+V	Residential social class	scclmean	none

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T	S+V	Residential housing pmeters	hsprmean	Yuan per square meter
T	S+V	Residential income	incomemean	Yuan per year
T	S+V	Are you satisfied with facilities such as large supermarkets	stflgsmmean	Points (0- 100)
T	S+V	Do you think it is convenient to shop nearby	stfshopmean	Points (0- 100)
T	S+V	How do you feel about your physical health	healthmean	Points (0- 100)
T	S+V	Public transportation accessibility	bussto_min	minute s (walki ng)
T	S+V	Parking lot accessibility	parlot_min	minute s (walki ng)
T	S+V	Car ownership	cartool	ratio (0–1)
T	S+V	Bicycle ownership	biketool	ratio (0–1)

(1) Variables Related to Scale

As noted earlier, among the many characteristics of supermarkets, size is an important factor influencing travel choices. Therefore, "scale" is chosen as the representative of the supply scale dimension to describe the characteristics of supermarket facilities in a 15-minute cycling living circle. "scale" refers to the building area.

- **Largest supermarket Size (scale_lgst):** This indicator represents the building area of the largest supermarket in the 15-minute cycling living circle where residents travel to. The data is sourced from the government urban renewal platform's building contour data. Large supermarkets typically offer a broader mix of businesses and spatial experiences, which are more attractive to residents (Figure 6.24).
- **Distance to Largest supermarket (Oddis_lgst):** This is the Euclidean distance from the residential quarter to the largest supermarket in the 15-minute cycling circle. It is calculated using the "Distance Matrix" tool in QGIS, measuring the straight-line distance between the residential center and the largest mall's POI.

This indicator reflects the spatial accessibility of large malls and helps analyze the interaction between facility attractiveness and travel distance, particularly useful for identifying districts with long-distance attraction patterns.

- **Size of the Nearest supermarket (scale_nst):** This indicator represents the building area of the nearest supermarket in the 15-minute cycling circle to the residential quarter. The method involves identifying the nearest supermarket from the residential center and extracting its size. This indicator reflects the attraction level of the "nearest available facility," helping assess whether the facilities within the living circle meet the shopping needs of residents.
- **Distance to the Nearest supermarket (Oddis_nst):** This is the Euclidean distance from the residential quarter to the nearest supermarket visited. The straight-line distance between the residential center and the nearest mall's POI is calculated using QGIS. This variable measures the convenience of reaching the nearest available facility within the living circle and is a key factor in determining whether residents choose to make short-distance trips, making it one of the core variables in green travel strategies.

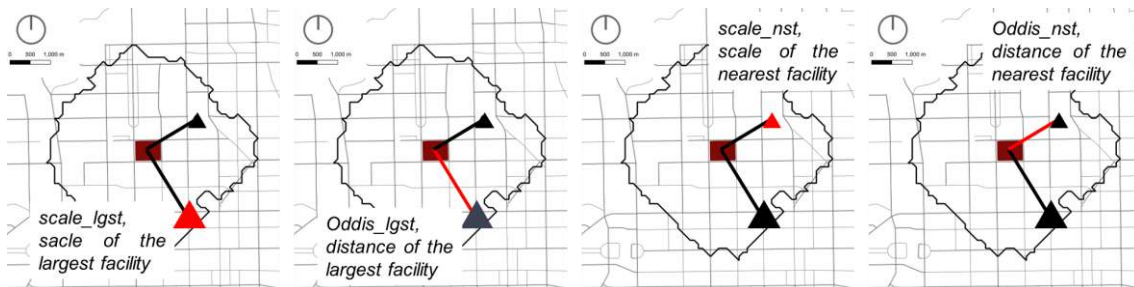


Figure 6.24 Visualization of four indicators (scale_lgst, oddis_lgst, scale_nst, oddis_nst)

- **Average Size (scale_ave):** This indicator represents the average size (square meters per mall) of all the malls visited within the 15-minute cycling circle. It is calculated by dividing the total building area by the number of malls. This indicator reflects the overall facility supply's average attractiveness within the living circle and is useful for analyzing the influence of facility supply on travel distance.

(2) Other Independent Variables

- **Maximum Operating Hours of Vegetable Markets (tmop_lgst):** This indicator represents the operating hours of the vegetable market with the longest operating

hours in the residential quarter's 15-minute cycling circle. It reflects the "time dimension" of the facility's service potential. Markets with longer operating hours can serve more diverse schedules and may attract more trips. This variable supplements the traditional "spatial accessibility" measurement and provides insights into the behavioral flexibility of long-distance trips. This variable is specific to vegetable markets since supermarkets have similar operating hours.

- **Operating Hours of the Nearest Vegetable Market (tmop_nst):** This indicator represents the operating hours of the nearest vegetable market in the residential quarter's 15-minute cycling circle. It reflects whether the primary choice for residents' basic service needs is time-friendly. If the nearest vegetable market has short operating hours, it may not meet the high-frequency demands, prompting residents to travel further to a market with better hours. Like the previous variable, this is specific to vegetable markets.
- **Average Operating Hours of Vegetable Markets (tmop_ave):** This indicator represents the average operating hours for all vegetable markets that residents visit, divided by the number of markets. This provides a comprehensive assessment of the time service level of facilities in the living circle. Like the previous indicators, this is specific to vegetable markets.
- **Number of Malls (nmbOD):** This indicator represents the number of malls that residents actually visit in their 15-minute cycling living circle. It quantifies the number of OD flow clusters formed between the residential quarter and different malls. This indicator also serves as a measure of the "degree centrality" in network analysis, reflecting the activity level of a residential quarter in the travel network^{[170][171]}. In this study, it primarily reflects the diversity of facility choices within the living circle, which can influence travel distance.
- **Primary supermarket Hierarchy (n3mkt):** This indicator represents the central hierarchy of the most frequently visited supermarket in the residential quarter across the entire city, reflecting the spatial directionality of residents' shopping behaviors. The hierarchy is based on the city's supermarket travel data, incorporating market principles and related studies^[174]. The indicator captures whether residents show a "far-end central concentration" behavior trend based on the mall's hierarchical level. Higher-ranked malls may indicate a tendency to cluster around distant central areas^[175].

$$n = \frac{\ln (R_{max}^2/R_i^2)}{\ln (k)} + 1 \quad (6-5)$$

among which, $k=3$, At 4 and 7 o'clock, it represents the market, administrative, and transportation principles in the central location theory. The results show that the same supermarket has similar levels in each principle. The market principle is taken as the k value in the following text, where R_{max} is the maximum radius of the entire market, which is two-thirds of the radius of the Tangshan built-up area, which is 5441.73 meters, and R_i is the average travel distance of consumers.

The total number of trips (nmbtrasz) refers to the total number of trips to the supermarket within the 15 minute cycling living circle of the residential quarter, which is the sum of the number of trips to all OD flow clusters in the residential quarter. This indicator can be likened to weighted centrality in network analysis, reflecting the total travel intensity of a residential node^[171]. This indicator can be used to measure the activity of shopping and travel within the living circle.

Living circle satisfaction (bktocity), this indicator represents the proportion of trips from residential quarters to supermarkets within the 15 minute cycling living circle to the total number of trips to supermarkets in the city (unit: none). Its meaning is: what proportion of all shopping behaviors occur within the local living circle, reflecting the spatial cohesion of residents' shopping behavior. This indicator measures the effectiveness of the living circle from the perspective of residents' daily behavior, based on the concept of "activity space" in urban behavioral geography, and closely related to the concept of "living circle satisfaction"^[176]. Relevant literature points out that this type of indicator is an important basis for evaluating the degree of local implementation of basic living behaviors^[178].

The number of supermarkets within the pedestrian living circle (nmbODw), which represents the actual number of supermarkets visited within the 15 minute pedestrian living circle of a residential quarter (unit:), that is, the number of terminal supermarkets that form an OD flow cluster with the residential quarter. This indicator measures the supply density and accessibility of supermarkets near residential quarters, which helps identify structural problems such as "hollowing out"^[178].

The total number of trips to supermarkets within the walking living circle (nmbtraszw) refers to the total number of trips from residential quarters to supermarkets

within a 15 minute walking living circle, which is the sum of the actual number of trips for each path in the OD flow cluster formed by residential quarters and different supermarkets. This indicator reflects the density of shopping trips within the pedestrian circle^[171].

Wktocity, which refers to the proportion of shopping trips from residential quarters to supermarkets within a 15 minute walk to the city's supermarkets (without units). The proportion of residents' total trips to supermarkets that occur within a 15 minute walking distance reflects the level of local satisfaction in the living circle, based on research results on the living circle^[178].

The satisfaction of the walking circle with the cycling circle (wktobk) refers to the proportion of all shopping trips within the 15 minute cycling circle in a residential quarter that also fall within its 15 minute walking circle (unit: none). Its essence is the spatial overlap between the cycling and walking living circles, used to measure to what extent the walking living circle carries the travel needs of the cycling circle. This indicator is an important reference for optimizing spatial organization and encouraging short distance travel^[178].

The average travel distance within the walking circle (dismeans), which represents the average Euclidean distance (in meters) from a residential quarter to a supermarket within a 15 minute walking circle. Calculate the distance from the centroid of the residential quarter to each terminal supermarket through QGIS, and calculate the weighted average of all walking trips. This indicator is used to evaluate the distance cost within the pedestrian circle^[175].

The scale preference coefficient (bstgmcity) reflects the strength of residents' preference for supermarket scale in their trips to supermarkets throughout the city (without units). It is obtained by fitting the relationship between the city's travel probability and supermarket scale in the form of an exponential function in the Huff model. The larger the numerical value, the more attractive the scale, which is an important perceptual variable to explain the phenomenon of "seeking distance over proximity". The calculation process of this indicator can be found in section 7.2.3 for research verification.

The distance attenuation coefficient (bstlmdcity), which reflects the sensitivity of residents to distance in their supermarket travel choices throughout the city (without units), is obtained by fitting the exponential attenuation function in the Huff model based on the city's travel data. The larger the coefficient value, the more inclined residents are

towards close range travel, while the smaller the coefficient value, the more tolerant residents are of long-distance travel. The theoretical basis originates from Huff (1963). The calculation process of this indicator can be found in section 7.2.3 for research verification.

Scale preference coefficient (bstgmbike), which represents the intensity of residents' preference for the size of supermarkets within a 15 minute cycling living circle (without units). This study is based on the modified Hough model for fitting, and obtains the scale parameter as the preference coefficient through the correspondence between actual travel behavior and facility scale. The higher the coefficient value, the more likely residents are to go to large supermarkets. Its theoretical basis stems from the assumption in the Huff model that "attraction increases with size". The calculation process of this indicator can be found in section 7.2.3 for research verification.

Distance attenuation coefficient - within the 15 minute cycling circle (bstldbike), this indicator represents the sensitivity of residents to distance (without units) when traveling to supermarkets within the 15 minute cycling circle. It is derived from the fitting of travel data within the 15 minute cycling circle and the Huff model. Compared with the city wide attenuation coefficient, this variable can better characterize the elasticity of green travel choices under the "15 minute cycling living circle". The calculation process of this indicator can be found in section 7.2.3 for research verification.

Commercial Corridor Distance (distcmwens), which represents the weighted average distance (in meters) from residential quarters to major commercial corridors. The calculation method is a weighted sum of 3/4 of the distance between the residential quarter and the Tangshan main transverse corridor and 1/4 of the distance between the longitudinal corridor. This indicator is used to measure whether residential quarters are adjacent to city level commercial corridors, reflecting the correlation between urban structural layout and commercial accessibility. Its design is based on the planning methods of public transportation and commercial corridors in the concepts of Transit Oriented Development (TOD) and Traditional Neighborhood Development (TND), which helps identify the structural disadvantages or advantageous locations of different types of residential quarters, and explore the attraction and aggregation effects of corridors on travel^[179]. Due to the layout of supermarkets along commercial corridors, and the scattered point like distribution of vegetable markets, there is no continuous axis like gathering on both sides of the two main commercial corridors in Tangshan. Therefore,

this indicator is a unique indicator for supermarkets, used to identify the dependence and accessibility of residential quarters to the city level commercial development main corridor.

Residential population density (*czzrk_smyx*), this indicator represents the total population density (people/square kilometer) within the residential land area. The data is sourced from the "Tangshan 15 Minute Convenient Living Circle Plan" and the number of residential households on the Anjuke website, adjusted in conjunction with community and residential boundaries. Population density, as one of the most fundamental social spatial variables, affects the intensity of facility usage within the living circle. This variable is also commonly used to control for population exposure effects and improve model robustness^[165].

Average age of residential quarter (*agemean*), which represents the average age of residents in the residential quarter (unit: year). Age structure is an important variable that affects differences in shopping demand. Related studies have shown that middle-aged and elderly people are more inclined to rely on neighborhood level businesses, while young and middle-aged people prefer larger scale purposeful facilities. Therefore, age structure may have a significant impact on travel distance and facility selection in their living circle^[178]. The calculation of the average age of residential quarters is based on the Tangshan satisfaction survey questionnaire. The questionnaire questions and optional options are: "What is your age? Under 20 years old | 20-29 years old | 30-39 years old | 40-49 years old | 50-59 years old | 60-69 years old | 70 years old and above, corresponding to 1 | 2 | 3 | 4 | 5 | 6 | 7". Please refer to the formula and pictures for details.

$$agemean = \frac{\sum_{i=1}^n age_i}{n} \quad (6-6)$$

Among them, *agemean* represents the average age of the residential quarter and is the mean age of the sample within the residential quarter; *n* represents the sample size within the residential quarter; *i* represents the sample; *age_i* represents the age of each sample, replaced by 1 to 7. The specific case is as follows: Firstly, based on the geographic coordinates of the questionnaire, the questionnaire is visualized in the form of point data in QGIS, with a total of 23105 points in the built-up area; Secondly, for each residential quarter, the number of internal points counted within the boundary of the residential quarter is 81; Again, calculate the age of these points; Finally, the average age of the residential quarter is the sum divided by 81. In statistics, if the number of questionnaire

samples (points) in a residential quarter is less than 10, it will be recorded as null. Other questionnaire based indicators in the study, such as the social class level of the residential quarter, will be treated using the same method and will not be repeated in the following text.

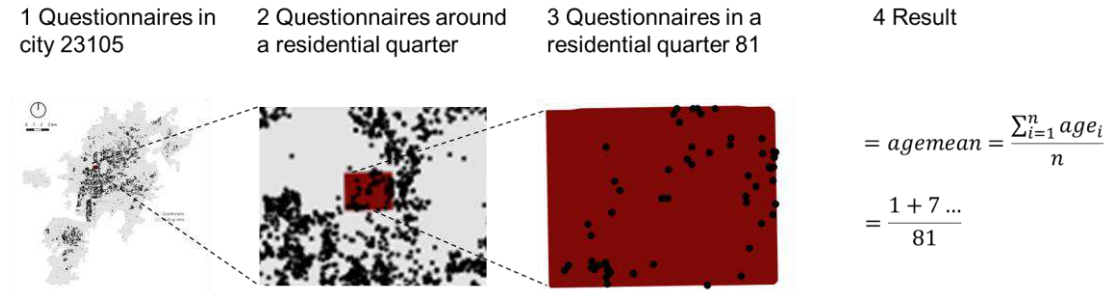


Figure 6.25 Indicator calculation based on geographic location questionnaire

The average social class level of residential quarters (scclmean), which represents the average social class (without unit) of residents in residential quarters. The calculation method is similar to the average age of the residential quarter, which is the average social class of the residents who answered the questionnaire sample in the residential quarter. Class structure is an important variable reflecting the consumption ability and commercial facility utilization ability of the living circle, especially in the layout of large commercial facilities, where the preferences and payment abilities of different class groups vary significantly. Previous studies have shown that the middle and high-income groups are more inclined to travel across social circles to higher-level commercial districts, while the low-income group relies more on nearby facilities^[177]. Therefore, this variable can be used to explain the behavior of "seeking distance from the near" or "satisfying the near". The calculation is based on the Tangshan satisfaction survey questionnaire, with the questionnaire question and optional options being: "Compared to peers, what is your socioeconomic status? High | Similar | Low |, corresponding to 1 | 2 | 3".

The average housing price in residential quarters (hsprmean), which represents the average housing price per square meter of residential land within the residential quarter, is sourced from the Anjuke website. Housing prices represent residents' purchasing power and facility demand levels, and residents are more likely to accept high-quality commercial facilities, which in turn affects travel distance and facility selection preferences^[178].

$$hsprmean = \frac{\sum_{i=1}^n houseprice_i}{n} \quad (6-7)$$

Among them, *hsprmean* represents the average housing price of residential quarters, which is the average housing price of Anjuke residential quarters within the residential quarter; *n* represents the sample size of Anjuke residential quarters within the residential quarter; *i* represents the sample of Anjuke residential quarter; *houseprice_i* represents the housing prices of each Anjuke community sample.

The average income of the residential quarter (*incomemean*), which represents the average annual household income (yuan) of the residential quarter, is one of the core variables for measuring the economic foundation of the living circle. The calculation method is similar to the average age of residential quarters, which is the average annual income of households that answer the questionnaire sample in the residential quarter. The income level directly affects the range of travel choices and business preferences of residents. Studies have shown that high-income groups are more inclined to choose large and complex commercial districts for centralized shopping, while low-income groups rely more on neighborhood level small commercial facilities^{[175][168]}. The addition of this variable helps to control the interference of socio-economic differences on facility usage behavior in regression analysis, and improves the explanatory power and accuracy of the model. The calculation is based on the Tangshan satisfaction survey questionnaire, with the following questionnaire questions and optional options: "What is the total annual income of your family (including the total income of the family members living together, including wages and year-end bonuses)? Less than 30000 yuan | 30000 to 49000 yuan | 50000 to 69000 yuan | 70000 to 99000 yuan | 10 to 199000 yuan | 200000 to 299000 yuan | 300000 to 499000 yuan | 500000 yuan or more, corresponding to 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8".

The mean satisfaction level of large supermarkets (*stflgsmmea*), which represents the satisfaction level (in points) of residents with the overall services of large supermarkets near their residential quarter, is calculated using a method similar to the average age of residential quarters. It is the mean satisfaction level of residents who answer questionnaires within the residential quarter. According to the Perceived Behavioral Control (PBC) dimension of the Theory of Planned Behavior, I feel that there are not enough/good supermarkets in my living circle, and satisfaction can be used as a perceived facility supply variable, which is an important mediating variable connecting

facility supply and behavioral feedback. High satisfaction and perception of facilities by residents may reduce outer circle travel. The calculation is based on the Tangshan satisfaction survey questionnaire, with the following questionnaire questions and optional options: "Are you satisfied with facilities such as large shopping centers? Very satisfied | Satisfied | Average | Not very satisfied | Very dissatisfied | Not familiar, corresponding to 100 | 80 | 60 | 40 | 20 | Blank without scoring".

The satisfaction level of nearby shopping (stfshopmea) represents the subjective satisfaction level (in points) of residents with the convenience of daily shopping within their living circle. The calculation method is similar to the average age of the residential quarter, and it is the average satisfaction level of the residents who answered the questionnaire sample in the residential quarter. This indicator reflects residents' subjective perception of whether the basic commercial infrastructure configuration in their living circle is sufficient, and lower satisfaction may encourage residents to travel across circles. As a perceptual variable in green travel research, this indicator helps to reveal the cognitive driving mechanisms behind facility usage behavior. The calculation is based on the Tangshan satisfaction survey questionnaire, and the questionnaire questions and optional options are: "Do you think it is convenient to shop nearby in daily life, such as convenience stores, grocery stores, and express delivery points? Very convenient | Convenient | General | Not very convenient | Very inconvenient | Not familiar, corresponding to 100 | 80 | 60 | 40 | 20 | Blank no score".

Healthmean is an indicator that represents the average score (points) of residents' subjective assessment of their own health status. The calculation method is similar to the average age of the residential quarter, and it is the average health status of the residents who answered the questionnaire sample in the residential quarter. Obtain through the questionnaire item "What do you think is your physical health status. The health status largely affects residents' travel radius and mode choices. Studies have shown that individuals with poor physical condition are more reliant on transportation or reduce their frequency of long-distance travel. Therefore, this variable can be used as a control variable. Based on the Tangshan satisfaction survey questionnaire, the questionnaire questions and optional options are: "Do you think your physical health condition is very good | good | average | not good | very bad, corresponding to 100 | 80 | 60 | 40 | 20".

Bus accessibility (bussto_min) is an indicator that represents the walking time (in minutes) required to travel from a residential quarter to the nearest bus stop. It is

calculated by dividing the shortest network distance from the centroid of the residential quarter to the bus stop by the walking speed. Higher accessibility of public transportation may enhance the convenience of travel outside the living circle.

Parking Lot Accessibility (*parlot_min*), which represents the walking time (in minutes) from the residential quarter to the nearest public parking lot. The calculation method is to divide the shortest network distance from the centroid of the residential quarter to the public parking lot by the walking speed. This indicator indirectly reflects whether residents are willing to engage in medium to long-distance travel.

Car ownership rate (*cartool*) refers to the proportion of residents in a residential quarter who own private cars to the total number of surveyed residents (without units). As a highly mobile mode of transportation, the ownership rate of cars is related to whether residents have the material foundation for cross circle travel. Please refer to section 6.2.1.3 for the calculation method.

Bike ownership rate (*biketool*) refers to the proportion of residents in a residential quarter who own bicycles and electric bicycles to the total number of surveyed residents (without units). The availability of bicycles affects whether residents have the ability to choose medium to long-distance green travel. Please refer to section 6.2.1.3 for the calculation method.

The density of green travel (such as walking and cycling) on the main roads within the 15 minute cycling circle of a residential quarter, where residents travel to the nearest vegetable market, is represented by the recent green travel density (*dengre_nst*). The calculation method is: green travel endpoint divided by the 50 meter buffer zone area of the main road. This indicator reflects the intensity of green travel atmosphere on the core travel path of the living circle, indirectly reflecting the support of the street environment for residents' green travel behavior. Due to the shorter average travel distance of the vegetable market compared to supermarkets, it may be more affected by the green travel environment. This indicator is unique to the vegetable market.

The recent non green travel density (*denngr_nst*) represents the density (per square kilometer) of non green travel behaviors (such as cars and buses) on the main roads within the 15 minute cycling circle of residential quarters leading to the nearest vegetable market. The calculation method is: the number of non green travel times divided by the 50 meter buffer zone area of the main road. This indicator is one of the measures of negative environmental exposure factors. High density non green travel areas may weaken

residents' willingness to choose cycling or walking, and increase the risk of marginalization of nearby facilities. This indicator is unique to the vegetable market.

6.2 Methods

The study uses a random forest regression model combined with partial dependence analysis to characterize the sensitivity threshold of environmental variables in the surrounding streets of different facility types to green travel (walking and cycling) behavior.

6.2.1 XGBoost training and variable importance identification

This study employs the XGBoost regression algorithm (detailed in Chapter 5) to build a regression model predicting the travel distance of residents within their living circle, based on facility accessibility-related variables. The model selects 31 candidate variables, including **scale_lgst** (the largest facility scale in the living circle), **Oddis_lgst** (the distance to the largest facility in the living circle), and **scale_nst** (the size of the nearest facility in the living circle), with the dependent variable being the average travel distance to facilities within the 15-minute cycling living circle (**distan_mean**).

Before model development, the Pearson correlation coefficient matrix was calculated for the independent variables, along with the target variable. The p-value was used to denote statistical significance, and a heatmap (range from [-1, 1]) was used to visually display the correlation strength and significance between variables (see figure). For highly correlated pairs of independent variables, one of the pair was removed. In the case of the supermarket dataset, the removed variable was **wktocity**, while for the market dataset, **bktocity** and **dismeanw** were removed.

During model development, missing values were handled using imputation. The Recursive Feature Elimination with Cross-Validation (RFECV) method was then used for feature selection, iterating through 5-fold cross-validation to eliminate insignificant variables and determine the optimal feature combination. The RFECV process employed the XGBoost regressor, with the following parameters: 200 trees, learning rate of 0.04, tree depth of 8, minimum child weight of 6, and **colsample_bytree** set to 0.7 (**n_estimators** = 200, **learning_rate** = 0.04, **max_depth** = 8, **min_child_weight** = 6, **colsample_bytree** = 0.7, **random_state** = 42).

The feature selection results indicated that the model achieved the highest R^2 when

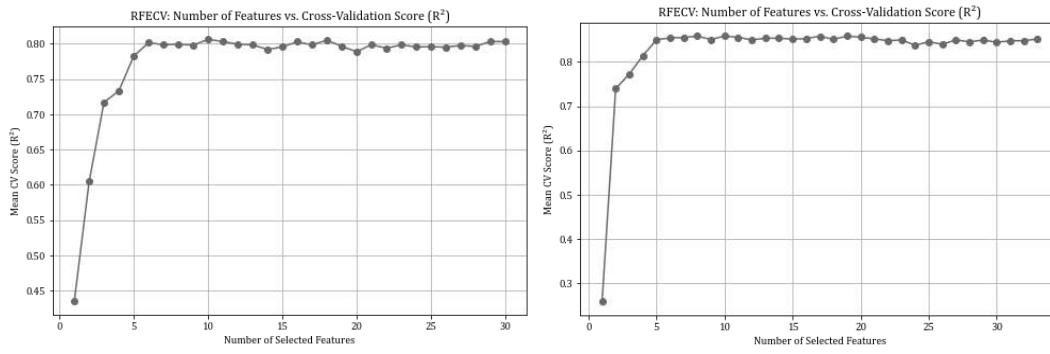


Figure 6.26 Feature selection using recursive feature elimination with cross-validation (RFECV) for supermarket (left) and vegetable market (right)

6.2.2 SHAP interpretation and short-distance travel threshold extraction

To further explore the mechanisms behind the influence of each feature on the predicted travel distance in the living circle, this study, after fitting the optimal XGBoost model, applies the SHAP (Shapley Additive Explanations) method to calculate the individual marginal contributions of the features. Specifically, the SHAP TreeExplainer tool is used to explain all samples, quantifying the contribution and direction of each feature in a single prediction result. The principles of the SHAP method are detailed in Section 5.2.2.

6.2.3 Living circle clustering by hierarchical method and SHAP value

To identify the heterogeneity in the green travel influence mechanisms across living circle samples, this study further performs clustering analysis based on the SHAP value matrix. The agglomerative clustering method (metric=Euclidean, linkage=Ward) is used to cluster samples in the SHAP space, and silhouette scores and Davies-Bouldin index (DBI) are computed for different cluster numbers ($k=2$ to 10). For supermarkets, the results show that when $k=4$, the DBI is minimized (0.832), and the silhouette score remains optimal (0.421). For vegetable markets, when $k=4$, the DBI is minimized (0.767), and the silhouette score remains optimal (0.373). This suggests that the clustering structure has good intra-cluster cohesion while maintaining excellent inter-cluster differentiation. Therefore, $k=4$ is selected as the final cluster number for both types of facilities, and the corresponding cluster labels are generated. The linkage method from SciPy (method=Ward) and dendrogram are used to visualize the clustering structure, demonstrating the hierarchical relationships among samples in the SHAP space.

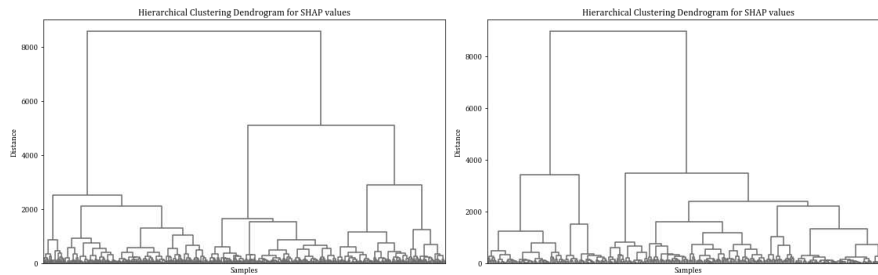


Figure 6.27 Hierarchical Clustering Dendrogram for supermarkets and vegetable markets based on SHAP values

The decision to use SHAP values for clustering rather than directly using the raw feature values is based on the following considerations:

- 1 **Feature Stability:** This study selects 10 core independent variables, which are moderate in number and have stable distributions. Clustering based directly on raw feature values can be easily influenced by differences in units and value ranges. In contrast, SHAP values reflect each feature's relative contribution to the model's prediction within the same unit of measurement, effectively mitigating scale issues.
- 2 **Linear Correlation Verification:** Subsequent SHAP local dependency curve analysis shows that most important independent variables exhibit an approximately linear relationship with the dependent variable (travel distance). Clustering based on SHAP values not only retains the correlation structure between raw features and the target variable but also aggregates samples by their contribution patterns, ensuring that samples within the same cluster exhibit highly consistent effects on key variables.
- 3 **Goal Orientation:** SHAP values directly quantify the marginal contribution of each feature to the prediction result. Clustering based on SHAP values helps identify groups of samples with different long-distance travel behavior patterns. This contribution-based clustering method is more targeted and interpretable, facilitating the formulation of differentiated green travel strategies.

The use of hierarchical clustering rather than k-means clustering in the SHAP value space aligns with the SHAP framework: SHAP values represent feature contribution vectors, and the hierarchical clustering process, which involves step-by-step merging, logically mirrors the cumulative contribution process.

6.2.4 Influence factor verification by travel structure diagram

Drawing on the "trip structure" approach from geography, this study independently validates the "factors influencing average travel distance within a living circle" from the perspective of spatial hierarchy. Unlike traditional planar distribution maps, which only depict the spatial location of residential quarters and facilities, travel structure maps abstract the planar nesting relationships into a tree structure, revealing the dominance and coverage relationships between facilities, as well as the affiliation and selection relationships between residential quarters with facilities of the same tier. This representation intuitively demonstrates the hierarchy and mobility of facility service areas, demonstrating whether a particular facility monopolizes surrounding residential quarters or whether residents have free choice among facilities of the same tier. This approach aligns with Alexander's discussion^[163] of whether different spaces are intertwined due to the provision and access of services in "The Tree of the City, " but this paper further emphasizes the spatial logic of facility dominance and resident dependence.

In addition, the travel structure approach, inspired by the Central Place Theory, the Davis model^{[167][168]}, and the research on the hierarchical structure of shopping trips by Chai Yanwei^[169] and others, simultaneously demonstrates the logical relationships between the "distance to the largest facility," the "distance to the closest facility," and the "average travel distance." It simplifies complex OD flow clusters into a clearly layered structure. It not only reveals the hierarchical differences in facility scale and location, depicts the interval characteristics of travel distances for each level of facility, but also explains the role of different facility types in determining average travel distances. Compared with traditional floor plans, the travel structure diagram offers greater explanatory power and visualization advantages, providing strong empirical support for the core concept that the distance to the largest facility and the distance to the closest facility within a living circle jointly determine average travel distances.

6.3 Regression results: importance and optimal ranges of variables to short-distance travels

6.3.1 Importance and optimal ranges of supermarket layout variable

The study identified 10 significant independent variables that affect the average travel distance to malls within the living circle. The distance to the largest supermarket

(Oddis_lgst) has the most significant impact on the average travel distance to malls (0.3359), followed by the distance to the nearest supermarket (Oddis_nst, 0.1697). The importance of the largest mall's scale (scale_lgst, 0.0567) is greater than that of the nearest mall's scale (scale_nst, 0.0441), suggesting that for supermarket trips, the largest supermarket rather than the nearest supermarket plays the dominant role. Additionally, the importance of the 15-minute walking circle satisfaction (wktobk, 0.1372) is nearly equal to that of the distance to the nearest mall, indicating that 15-minute walking circle planning has a substantial influence on travel behavior. The importance of the distance to the nearest key commercial corridor (distcmwens) (0.0615) falls between distance and scale, suggesting that key commercial corridors play an intermediary role in guiding residents' trips to malls. The spatial accessibility of these corridors partly determines the attractiveness of malls. This emphasizes that, in optimizing the layout of malls within living circles, one should not only focus on the characteristics of the supermarket itself but also consider the city's commercial corridor system and strengthen the interaction between primary commercial corridors and high-level commercial service nodes to reduce long-distance travel.

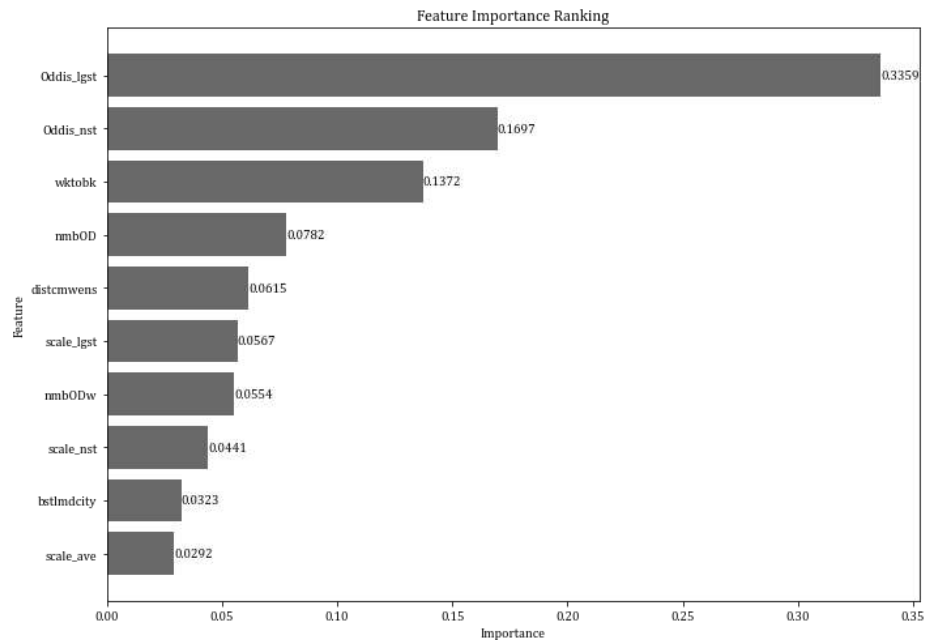


Figure 6.28 Ranking of importance of variables in the 15-minute cycling circle for supermarket travel distance

These 10 independent variables belong to four dimensions (Figure 6.29). The most important dimension is "Distance and Density," followed by "Scale," and finally,

"Attitude." The influence mechanisms of these 10 variables on the average travel distance in the living circle can be categorized into three types: linear positive correlation, linear negative correlation, and nonlinear correlation. The maximum supermarket distance (Oddis_lgst) and the nearest supermarket distance (Oddis_nst) exhibit a linear positive correlation, with travel distances becoming larger beyond 1981 and 1607 meters, respectively, exceeding the citywide average. The 15-minute walking circle satisfaction (wktobk) is categorized as a linear negative correlation, meaning that when the proportion of trips within the 15-minute walking circle is lower than 0.19, the travel distance is longer. The impact of the number of malls within the 15-minute cycling circle (nmbOD) on the average travel distance is nonlinear. Both high and low values of this variable can lead to long-distance travel, and when the number of malls in the walking circle is fewer than 2, long-distance travel is more likely. This finding provides valuable insights for urban planning. Nonlinear correlation also appears in the distance to important commercial corridors (distcmwens), with distances between 721 and 5567 meters leading to longer travel distances, indicating that people are willing to travel farther to reach higher-quality supermarket resources close to important commercial corridors, reflecting the threshold effect of commercial corridor aggregation and guiding in the spatial structure.

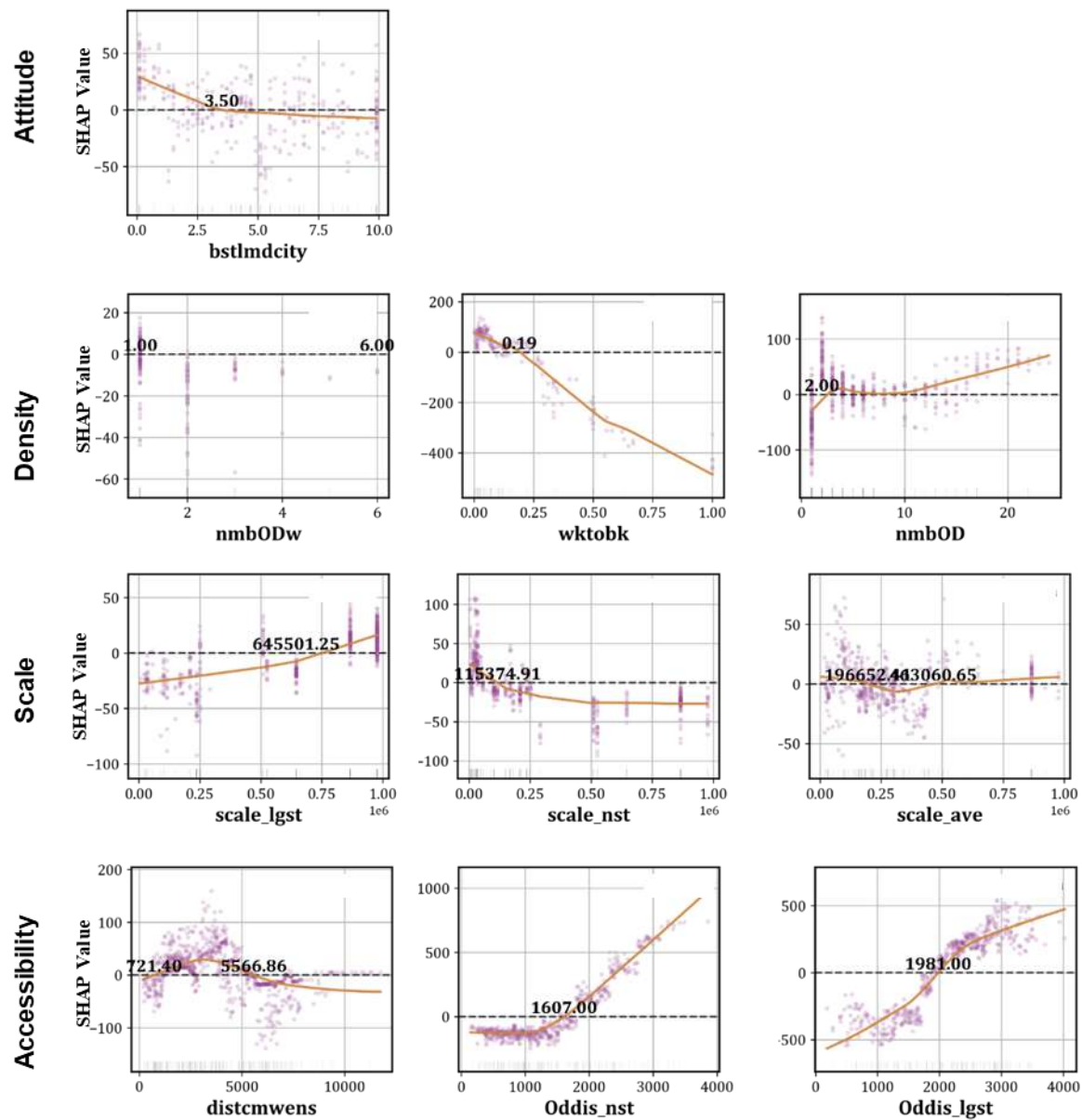


Figure 6.29 SHAP values of influencing factors for supermarket average travel distance

For each supermarket in the living circle, neither "distance" nor "scale" alone can capture its spatial characteristics. Its layout should be described by the combined "distance + scale." Therefore, based on SHAP interaction dimension analysis, the combined "distance + scale" characteristics of sample malls were mapped and the correlation with long-distance travel was discussed to provide actionable recommendations for living circle planning. We analyzed two types of malls: the largest supermarket within the living circle and the nearest mall.

For the largest mall, the combined effect of scale and distance significantly influences residents' travel distance. When the size of the largest supermarket is large

(greater than 600,000 m², red), it has a strong travel attraction, effectively attracting residents from nearby areas within a 2000-meter range and reducing the average travel distance. Additionally, it can attract residents from more distant areas when the distance exceeds 2000 meters, reflecting the mall's cross-zone radiation capability. This shows that within a 2000-meter living circle, increasing the size of existing malls (from blue to purple and red) can significantly improve residents' long-distance travel behavior and enhance the service capacity and accessibility of the living circle.

For the nearest mall, the combined effect of scale and distance is still significant. When the size of the nearest supermarket exceeds 600,000 m² and the distance exceeds 2000 meters, it leads to long-distance travel behavior for residents. When the distance is less than 2000 meters, it leads to short-distance travel, similar to the threshold for the largest mall. When the nearest supermarket is small, its distance within the living circle hardly affects residents' travel distances. This further proves that physical proximity alone is not sufficient to meet residents' needs, and the improvement of facility hierarchy is key to optimizing the travel structure within living circles (Figure 6.30).

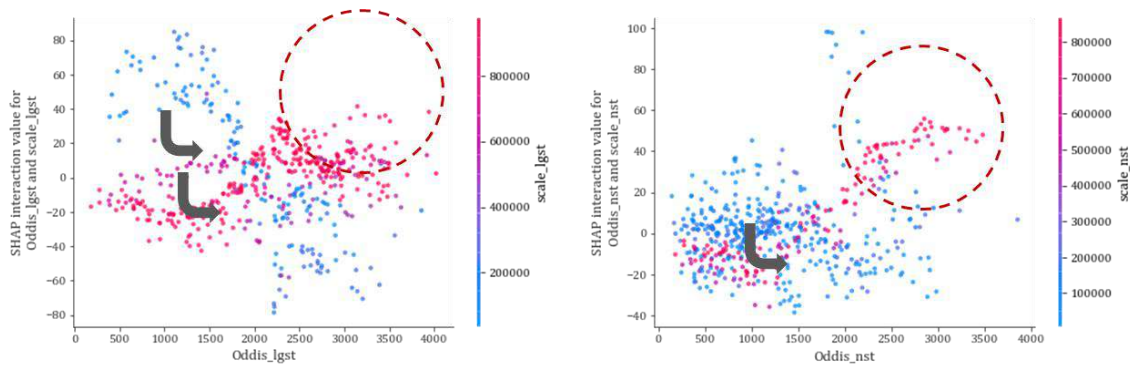


Figure 6.30 Interaction analysis of scale and distance for the largest and nearest supermarket

6.3.2 Importance and optimal ranges of vegetable market layout variable

Ten independent variable characteristics significantly influence the average travel distance to vegetable markets within the living circle. The distance to the nearest vegetable market (Oddis_nst) has the largest impact on the average travel distance to vegetable markets (0.2787), followed by the distance to the largest vegetable market (Oddis_lgst, 0.1537). The number of vegetable markets is more important than scale, with four indicators related to the number (nmbOD, nmbODw, nmbtrasz, nmbtrasz), and one indicator related to scale (bstgmbike). The importance of the 15-minute walking circle

satisfaction (wktobk, 0.2561) is almost equal to that of the distance to the nearest vegetable market, indicating that the arrangement of vegetable markets within the 15-minute walking circle is important for short-distance travel. It can be inferred that for vegetable market trips, it is the nearest vegetable market, rather than the largest one, that plays the dominant role. The green travel environment of the living circle's nearest vegetable market flow cluster (dengre_nst) also has some impact on the vegetable market's travel distance.

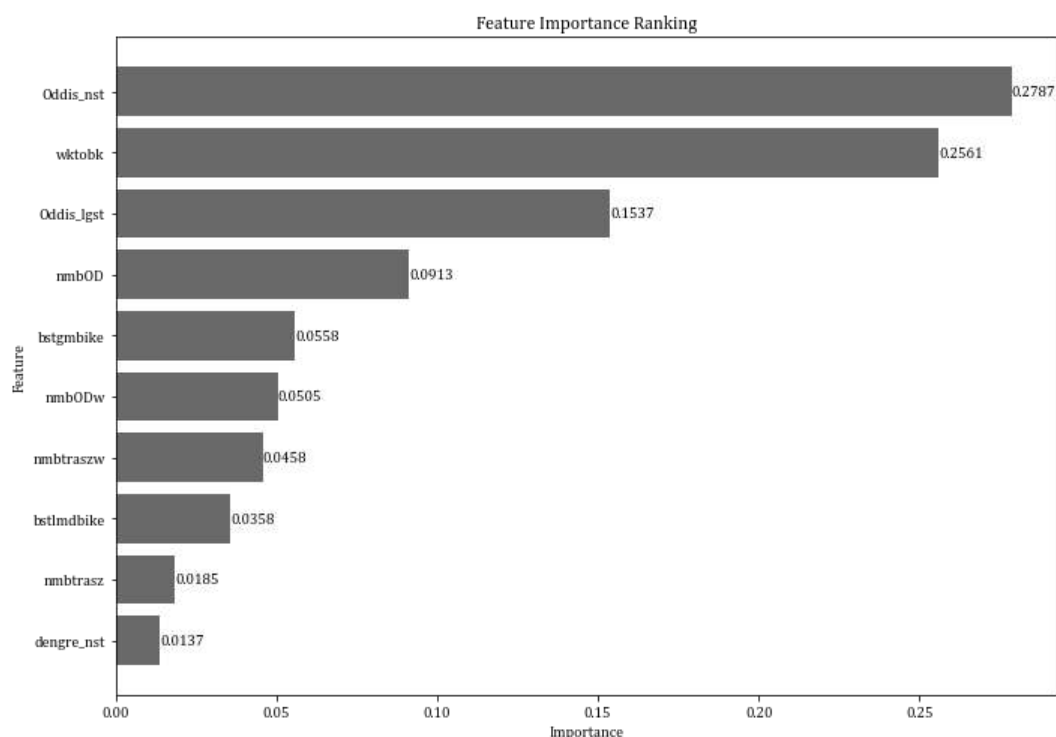


Figure 6.31 Ranking of feature importance for average travel distance to vegetable markets in the 15-minute cycling circle

These ten independent variables belong to four dimensions (Figure 6.32). The most important dimension is "Distance and Density," followed by "Attitude," and lastly "Road Conditions." The influence mechanisms of these ten variables on the average travel distance within the living circle can be categorized into three types: linear positive correlation, linear negative correlation, and nonlinear correlation. The distance to the nearest vegetable market (Oddis_nst) and the distance to the largest vegetable market (Oddis_lgst) exhibit a linear positive correlation, with travel distances becoming longer beyond 1725 and 1831 meters, respectively, exceeding the citywide average. The 15-

minute walking circle satisfaction (wktobk) is categorized as a linear negative correlation, meaning that when the proportion of trips within the 15-minute walking circle is lower than 0.43, the travel distance is longer. The number of vegetable market trips in the 15-minute walking circle (nmbtraszw) is inversely related to the travel distance, with fewer than three trips resulting in longer travel distances. Conversely, the number of vegetable markets and the number of trips in the 15-minute cycling circle have a relationship where the average travel distance decreases and then increases. The green travel environment, represented by the nearest flow cluster's walking and cycling density (dengre_nst), has a fluctuating marginal effect on the travel distance in the low-density range (0-2539), suggesting that the guidance of green travel environments on travel decisions is still unclear.

When the scale sensitivity coefficient (residents' sensitivity to facility scale) is at a low to medium level (0.17 to 0.58), residents are likely to abandon the nearest but smaller vegetable market and travel across zones to visit larger, more distant vegetable markets, which significantly increases the average travel distance. However, when the scale sensitivity coefficient increases further (greater than 0.58), residents' sensitivity to vegetable market size reaches a high level, but they also face the reality of travel costs, making their decisions more complex and diversified: some residents will still travel long distances across zones to find larger facilities, while others will choose a compromise due to time costs or transportation constraints. There is also the possibility that a large vegetable market is nearby, causing SHAP values to exhibit significant volatility (alternating positive and negative). Overall, the travel distance to vegetable markets is influenced by multiple factors, with the interaction of "spatial proximity," "living circle coverage," and "green travel support" jointly shaping residents' actual travel radius and living circle dependence structure.

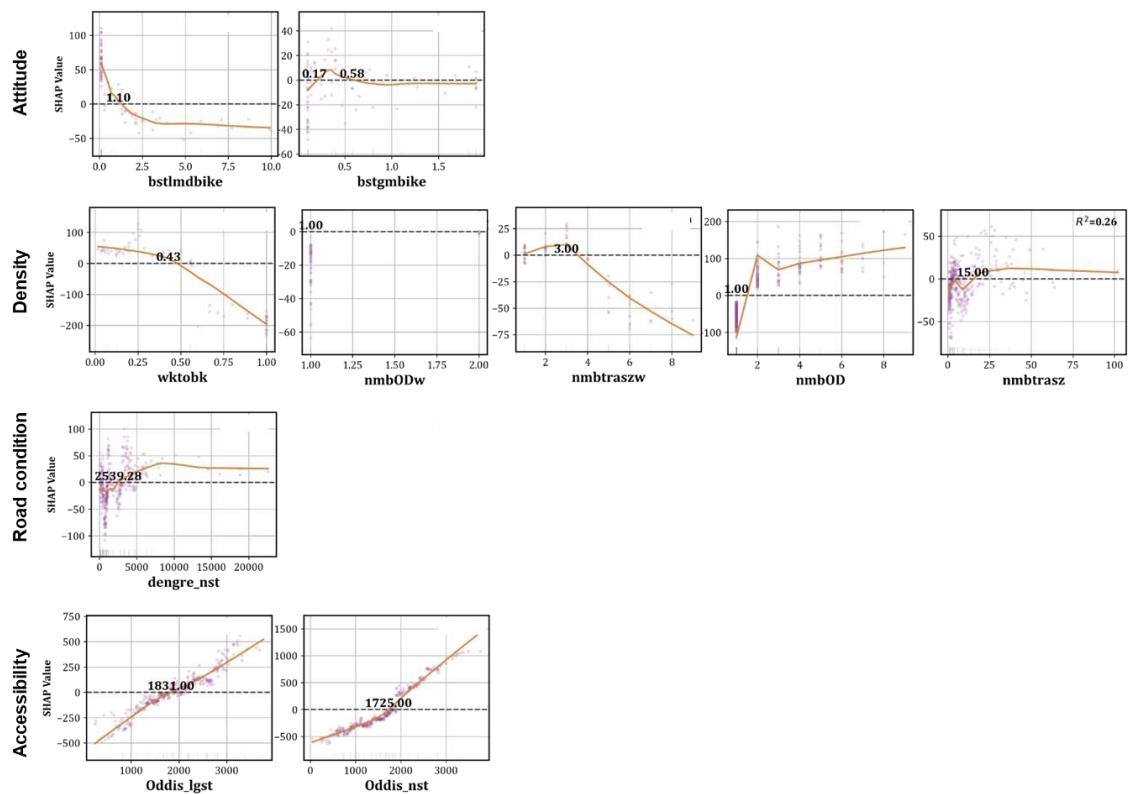


Figure 6.32 SHAP values of influencing factors for vegetable market average travel distance

The SHAP interaction plot on the left shows that when the distance to the nearest vegetable market (Oddis_nst) is less than 1800 meters, the impact on travel is minimal. When the distance to the nearest vegetable market is between 1800 and 2000 meters and the distance to the largest vegetable market is greater than 2000 meters, the living circle travel distance is longer. However, when the distance exceeds 2000 meters, the marginal contribution turns significantly positive, becoming a key variable in increasing travel distance. Furthermore, this variable has a significant interaction with the distance to the largest vegetable market (Oddis_lgst): when both the nearest and largest vegetable markets are far away, the travel burden is heaviest. However, when the nearest vegetable market is far away but the largest vegetable market is relatively close, some travel demand can be met by alternative, larger, nearby target markets, alleviating overall distance pressure. This result suggests that "convenient services" within the living circle remain the primary factor in shortening travel distances, while large-scale facilities can play a complementary role under certain conditions.

The SHAP interaction plot (right) reveals a significant nonlinear interaction between the distance to the nearest vegetable market (Oddis_nst) and the satisfaction level within

the 15-minute walking circle (wktobk) on travel behavior. When the distance to the nearest vegetable market is less than 1000 meters and the satisfaction level is less than 0.3, long-distance trips are observed. However, when the satisfaction level is greater than 0.3, trip distances are significantly shortened. This suggests that when the service level of the walking circle is low, nearby facilities struggle to function effectively, potentially increasing trip distances. Conversely, when walking accessibility is good, the service capacity of nearby vegetable markets is effectively unleashed, significantly shortening trip distances. Spatial proximity alone is insufficient to ensure the effectiveness of living circle services; the coordinated optimization of the walking environment and the distribution of facilities is the key to controlling long-distance trips. This may be because multiple nearby vegetable markets are necessary to ensure sufficient convenience for each residential quarter. Tangshan residential quarters are large, approximately 500 meters square. "Close" on one side may mean "far" on another. A balanced, multi-faceted layout within the walking circle ensures overall proximity of vegetable markets and shortens the average trip distance for all residential quarters (Figure 6.33).

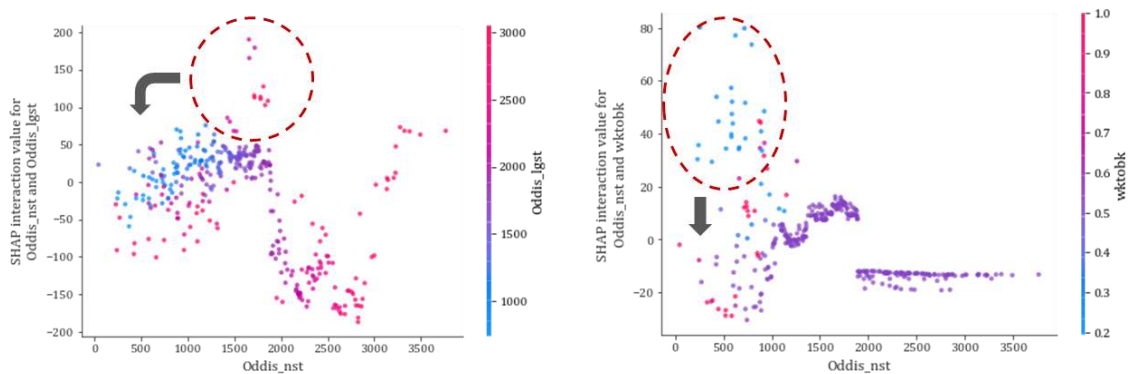


Figure 6.33 Analysis of recent interactions between the vegetable market and other features

6.4 Clustering results: four living circle clusters and characteristics

6.4.1 Facility layout-travel of clustering results of supermarket living circles

Since interaction features can only analyze the impact of two independent variables on the average travel distance, we classified 533 samples using hierarchical clustering and SHAP values to comprehensively analyze the correlation between living circle variables and average travel distance.

Among the four types of living circles (533 samples), the average travel distance to supermarkets in the fourth type (2929.18m) is the farthest, and the number of samples is the smallest (48). The first type of living circle has the shortest average travel distance (1551.85m) and the most samples (219). The second and third types have medium average travel distances and sample sizes.

Table 6.14 Clustered mean values of average travel distance to supermarkets across four living circle types

cluster	cluster_count	distan_mean_avg (m)
1	219	1551.85
2	171	2128.92
3	95	2372.50
4	48	2949.18

The spatial distribution of the four living circles shows a pattern from the city center to the periphery: **First Type** → **Second Type** → **Third Type** → **Fourth Type**, corresponding to “**traditional city center residential quarters**,” “**residential quarters near subcenters**,” “**peripheral traffic areas**,” and “**new residential quarters near the city edge**.” This helps us understand the phenomenon in the second type of living circle, where supermarket trips rely on medium- and long-distance supermarkets. This is because in these living circles, the supermarkets are close to small ones (near the residential quarter) and large ones (in the city center). Combined with convenient transportation between the residential quarter and the traditional city center, some residents prefer to travel longer distances to the city center for shopping. The first type of living circle enjoys the most city center resources with more and larger supermarkets. The third type is mostly located near main roads at the city’s edge, with balanced supermarket sizes and medium travel distances. The fourth type is located at the transition zone between urban and rural areas, showing the problem of separation between residential and commercial spaces, with remote supermarkets and longer travel distances.

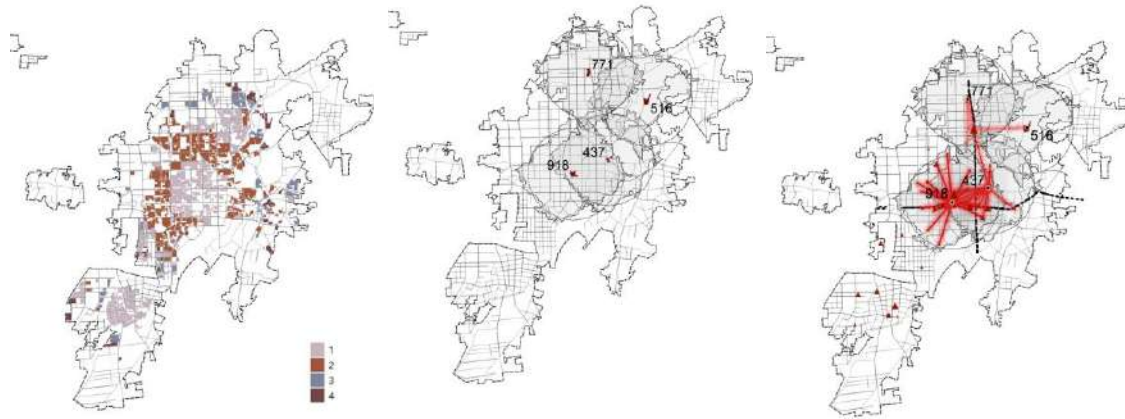


Figure 6.34 Four types of living circle distribution

Figure 6.35 Four living circle samples

Figure 6.36 Residential quarter-supermarket flow cluster for four samples

From the four types of living circles, one sample was selected for visualizing the residential quarter-supermarket flow cluster, and the spatial prototype of supermarket distribution in these living circles was extracted (Figure 6.37, Figure 6.38). The supermarket travel behavior shows a "corridor-like" feature (the two black dashed lines represent the two major commercial corridors in Tangshan). On one hand, traditional large supermarkets, new large supermarkets, and peripheral supermarkets are all located along these two major commercial corridors. On the other hand, these corridors are tightly coupled with the city's main road network and public transportation system, strengthening their dominant role in the city's overall commercial movement structure. The overlap of supermarket facilities with transportation corridors not only enhances the accessibility of the corridor areas but also makes supermarket travel within the living circle show the organizational characteristics of **"gathering along corridors and converging towards corridors."** Based on location, we can summarize: The first type of living circle has almost no long-distance trips; the second type relies on long-distance trips due to remote high-level supermarkets; the third type has long-distance trips due to low density; and the fourth type has long-distance trips due to the separation of residential and commercial spaces.

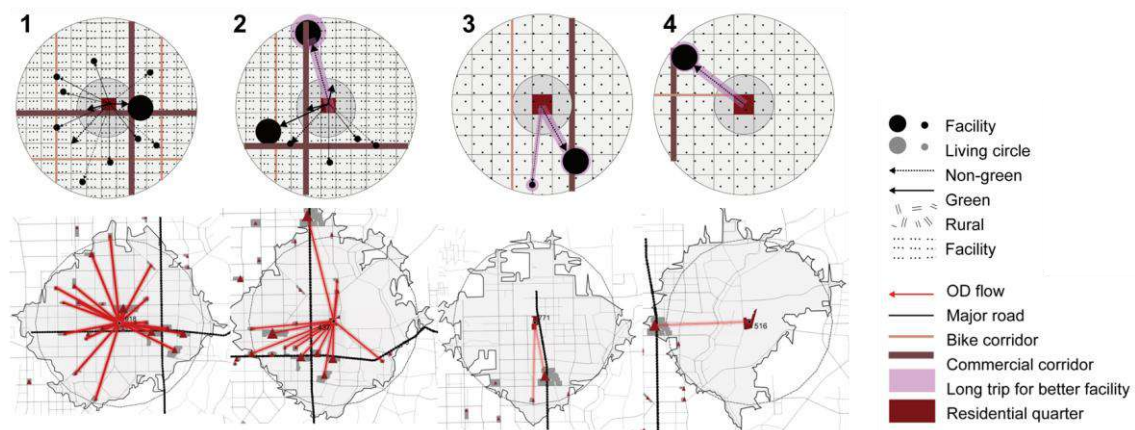


Figure 6.37 Supermarket travel living circle samples and prototype extraction

Based on the radar chart, the first type of living circle (219 samples) overall shows a strong convenience and balanced layout. Its average supermarket travel distance is 1552 meters, significantly lower than the overall sample average of 2009 meters, indicating good accessibility. Residents have more travel destinations ($nmbOD = 5.87$), and the activity level in the walking circle is also higher ($nmbODw = 1.79$, $wktobk = 0.25$), indicating strong daily service capacity within the living circle. The largest supermarket in this type of living circle is only 1288.54 meters away, and both the nearby supermarket size and the average size are relatively small, reflecting a multi-point distribution pattern built with medium- and small-sized facilities. Overall, the supermarket layout has the characteristics of high density and balance, which may correspond to a “**multi-core**” living circle model.

The second type of living circle (171 samples) has a medium to distant travel distance (2129 meters) but performs well in facility scale indicators. This type of living circle relies on a few large supermarkets, with the largest supermarket having a scale of 776,000 square meters, significantly higher than other types. In contrast, the nearest supermarket is only 124,000 square meters, presenting a “**large far, small near**” spatial pattern. The cycling circle in this type has a wide coverage ($nmbOD = 8.04$), but the walking circle's service capacity is weak ($wktobk = 0.11$), indicating that residents' travel is highly dependent on medium- and long-distance large supermarkets. Overall, the layout is dominated by large supermarkets, and there is insufficient local convenience, making this a “**near-village leakage**” living circle.

CHAPTER 6 CORRELATION BETWEEN SINGLE-TYPE LONG-DISTANCE TRAVEL CHOICE
AND FACILITY LAYOUT

Table 6.15 Mean values of supermarket layout characteristics across four living circle types

cluster	bstlmd city	distcm wens	nmbO Dw	wkt obk	scale_ lgst	Oddis _lgst	scale_ nst	Oddis _nst	scale_ ave	nmb OD
1	3.73	3649.6 9	1.79	0.25	62426 9.85	1288.5 4	34147 3.84	979.2 9	27162 1.64	5.87
2	5.16	2222.4 5	1.53	0.11	77559 5.02	2698.8 8	12385 1.73	1000. 45	23552 5.85	8.04
3	6.44	3558.9	—	—	50614 4.62	2386	39419 5.87	2237. 73	38828 3.24	1.89
4	6.39	4297.1	—	—	65009 9.5	3124.4	41480 1.83	2784. 52	49738 7.72	1.79

The third type of living circle (95 in total) is at a moderate level in terms of travel distance (2373 meters) and facility scale, with the largest supermarket distance being 2386 meters and the largest supermarket scale being 506000 square meters. The difference in scale between the farthest and nearest supermarkets is not significant, reflecting that residents have more concentrated choices and the overall spatial structure is relatively compact and balanced. Although there are few travel points (nmbODw=0, nmbOD=1.89), this type of living circle may rely on a few attractive supermarkets to achieve travel purposes. But from the overall trend, it is more likely to manifest as a low-density, sparsely populated "fan-shaped radiation" living circle form.

The fourth type of living circle (48 in total) has the longest travel distance, with an average of 2929 meters, significantly higher than other types, indicating that residents need to cross large distances to complete daily shopping. The number of supermarkets in this type of living circle is the smallest (nmbOD=1.79), with sparse selection and a lack of pedestrian circle coverage. The maximum distance to the supermarket is 3124.4 meters, and the nearest supermarket is as high as 2784.5 meters. The farthest distance to important commercial corridors is 4297.1 meters, reflecting the typical spatial feature of "facility hollowing out". Although the average size of its supermarkets is relatively high, this reflects the passive choice of residents to travel far to large supermarkets. Overall, this type of living circle belongs to the area with a lack of facility services or an edge type, with a high dependence on distant supermarkets, highlighting the significant lack of accessibility and spatial fairness of facilities within the living circle.

Table 6.16 Summary of supermarket layout characteristics across four living circle types

Category	Travel Distance	Number of Supermarkets	Mall Scale Characteristics	Walking Circle Satisfaction	Mall Layout-Travel Pattern	Reasons for Long-Distance Travel	Corresponding Spatial Layout Type of Living circle
Type ①: “Large Nearby-Small Distant then Short-Distance Convenience” Living Circle	Shortest	Largest	Medium scale, proximity-based	Relatively high (0.25)	High-density balanced convenience-oriented	——	Multi-core type, peri-core hybrid type
Type ②: “Small Nearby-Large Distant then Bypassing Behavior” Living Circle	Medium	Moderately high	Large distant, small nearby	Relatively low (0.11)	Mid-to-far large supermarket dependency	Long-distance travel due to remoteness of high-end malls	Peri-urban porous type
Type ③: “Flat Structure then Balanced Distance” Living Circle	Medium	Moderately low	Balanced yet concentrated	Walking circle none	Low-density balanced limited-choice type	Long-distance travel due to low density	Radial layout type
Type ④: “Neighborhood Absence then Distal Dependency” Living Circle	Farthest	Fewest	Large yet distant	Walking circle none	Passive distal supermarket selection type	Long-distance travel due to residential-commercial separation	Hollow-core type

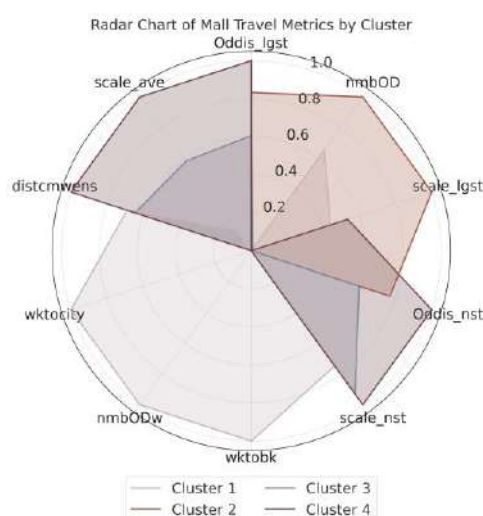


Figure 6.38 Radar chart of supermarket layout features (normalized) for 4 types of living circles

6.4.2 Facility layout-travel of clustering results of vegetable market living circles

According to the data in the table, among the four types of living circles (a total of 357), the average travel distance to a vegetable market for the entire sample is 1,855 meters. The second type of living circle has the longest travel distance, with an average of 2,899.56 meters, and the fewest samples (38), indicating that this type of living circle has a significant disadvantage in terms of service accessibility. The third type of living circle has the shortest travel distance, only 839.17 meters, indicating that residents can meet their vegetable market needs within a relatively close range. However, its sample size is also relatively small (36), suggesting a strong geographical concentration. The fourth and first types of living circles have relatively large sample sizes, with 214 and 69 samples, respectively, and their travel distances are intermediate, at 1,705.50 meters and 2,273.84 meters, respectively. Overall, a composite gradient distribution of living circle types is observed in terms of travel distance and sample size.

Table 6.17 Clustered mean values of average travel distance to vegetable markets across four living circle types

cluster	cluster_count	distan_mean_avg (m)
1	69	2273.839185
2	38	2899.555424
3	36	839.17195
4	214	1705.497686

The spatial distribution of the four types of living circles is as follows. The third type, with the shortest travel distance, is scattered across various locations (city center, urban fringe, and rural areas) rather than concentrated in the city center. Contrary to common sense, this may be because these residential quarters are near large vegetable markets, making it convenient to transport agricultural products. The second type, with the longest travel distance, is sparsely populated and located on the city fringe. Residents tend to choose the outer market over the city center, forcing them to travel further. The fourth type, with a medium travel distance, is the most numerous and widely distributed, covering more than half of the residential quarter. This suggests that vegetable markets are more evenly distributed and these residential quarters have convenient access to them. The first type, with a medium travel distance, is also located on the city fringe, but compared to the second type, it is closer to major transportation routes and the city center and is more likely to choose the inner-city market.

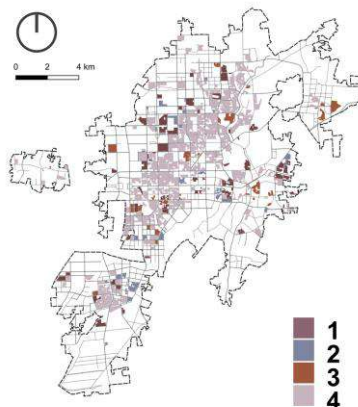


Figure 6.39 Distribution of four types of living circles figure

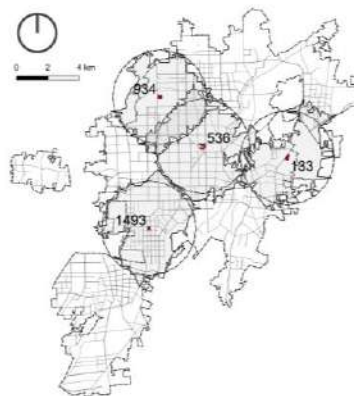


Figure 6.40 Four living circle samples figure

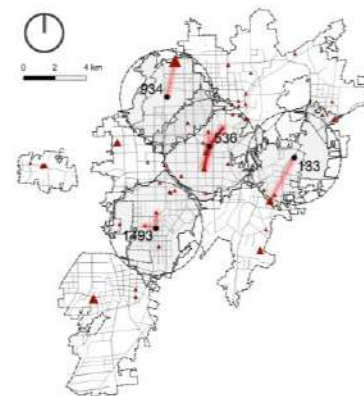


Figure 6.41 Residential quarter-vegetable market flow clusters of four samples

One sample from each of the four living circles was selected to visualize the residential quarter-vegetable market flow clusters and extract spatial prototypes for the distribution of vegetable markets within each of these living circles (Figure 6.42, Figure 6.43). These four living circles prioritize proximity and are influenced by the density of nearby vegetable markets and the travel environment. On the one hand, due to the even distribution of vegetable markets, a few large vegetable markets are located on the city fringes, but the number of residential quarters in these fringes is also relatively small. On the other hand, due to the relatively small differences in vegetable market services,

residential quarters do not need to waste travel costs to more distant facilities. Considering the location, the third living circle is compact and convenient, with almost no long-distance travel; the second living circle is characterized by the separation of residential and commercial areas and a preference for peripheral vegetable markets, which leads to long-distance travel; the fourth living circle is moderate, with relatively few long-distance trips; and the first living circle is characterized by low density, which leads to long-distance travel.

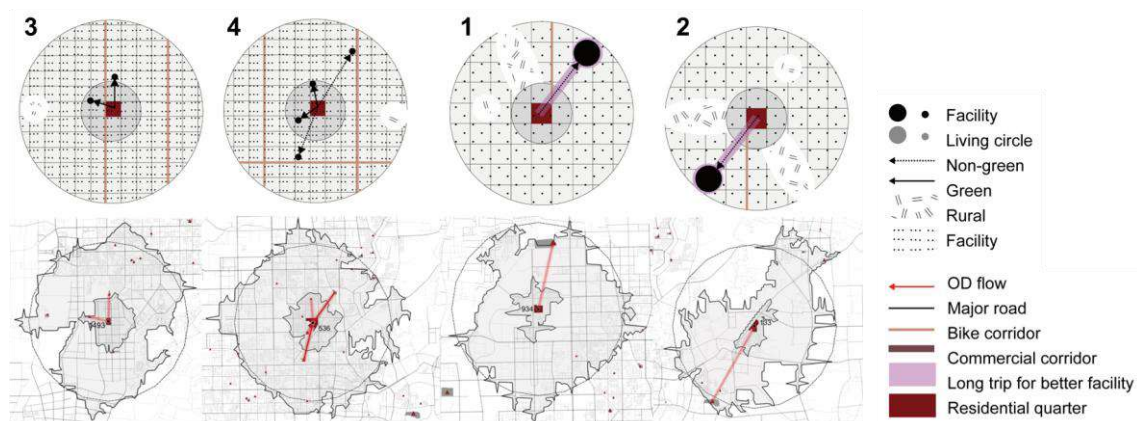


Figure 6.42 Sample and prototype extraction of four types of vegetable market travel living circles

Based on radar chart analysis and analysis of relevant vegetable market travel characteristics, the first type of living circle (69 in total) exhibits moderately remote vegetable market access with an average travel distance (2,274 meters), slightly higher than the city average (1,855 meters). Facilities are relatively balanced but slightly sparsely distributed. Residents in this type of living circle have a high number of trips ($nmbtrasz = 7.28$) but a limited number of facilities ($nmbOD = 1.49$). The distances to both the nearest and largest vegetable markets exceed 2,100 meters, reflecting insufficient facility density. Residents still experience significant cross-circle travel for shopping. This type of living circle corresponds to a "medium-distance dependency" model, where residents rely on the medium distance of facilities and relatively frequent trips to meet their basic needs for vegetable market services.

The second type of living circle (38 in total) exhibits a clear long-distance dependency, with the longest average vegetable market travel distance (2,900 meters), significantly higher than the city average. The distances between the largest and nearest vegetable markets are both close to 3,000 meters, indicating that residents lack readily

accessible facilities and must rely on extremely distant vegetable markets for basic needs. Furthermore, residents have a high sensitivity to scale ($bstgmbike = 1.33$), and this significantly increased preference for facility scale may further drive long-distance travel. However, the distribution of vegetable market sizes (large vegetable markets are located on the city's fringes, resulting in high scale sensitivity) and the SHAP plot (a $bstgmbike$ of 1.33 results in positive and negative SHAP value fluctuations) indicate that scale has a limited impact on travel distance. OD flow cluster analysis shows that when the distance to a central vegetable market is similar to that to a peripheral vegetable market, but the peripheral market is slightly larger and higher quality, these residential quarters tend to choose the peripheral vegetable market as their primary destination. This type of living circle is typically characterized by "distant peripheral vegetable market dependence," with extremely dispersed facilities resulting in poor service quality and accessibility.

Table 6.18 Mean characteristics of vegetable market layouts in four living circles

cluster	bstlmd bike	bstgm bike	nmb ODw	nmbt rasz w	wkto bk	Oddis_1 gst	Oddis _nst	nmb OD	nmb tras z	dengre_ nst
1	2.66	0.48	—	—	—	2264.43	2184.2	1.49	7.28	2039.56
2	0.1	1.33	—	—	—	2924.32	2917.3 7	1.21	5.08	2058.71
3	5.3	0.14	1	2.43	0.95	764.28	752.5	1.22	3.39	1591.68
4	1.15	0.5	1.19	3.79	0.29	1811.54	1282.5 1	2.64	11.5 2	2494.39

The third type of living circle (36 in total) exhibits prominent proximity and convenience. The average travel distance to the vegetable market is extremely short (839 meters), significantly lower than the city average, demonstrating excellent facility layout and service accessibility. This type of living circle has extremely high walking distance satisfaction ($wkto bk = 0.95$), a highly compact facility layout ($Oddis\_nst = 753$ meters), and an ideal green travel environment ($dengre\_nst = 1592$). Residents can meet their daily vegetable market needs within walking or cycling distance. This is a typical "compact and convenient" living circle, likely corresponding to city centers or high-density residential quarters.

The fourth type of living circle (214 in total) has a moderate average travel distance to the market (1,706 meters), slightly below the overall average. It also features a relatively balanced layout of facilities and travel patterns. Residents have the highest number of trips ($nmbtrasz = 11.52$) and the greatest number of facilities ($nmbOD = 2.64$),

reflecting a multi-point, dispersed spatial pattern with relatively even infrastructure coverage. Furthermore, this living circle has average pedestrian satisfaction ($wktobk = 0.29$) and the best support for green travel ($dengre\_nst = 2494$), indicating that despite moderate travel distances, residents benefit from high-quality walking and cycling infrastructure, resulting in low travel costs. This type of living circle can be defined as "dispersed facilities but green accessibility," with facilities well integrated into the green transportation network, resulting in a relatively balanced and sustainable overall spatial pattern.

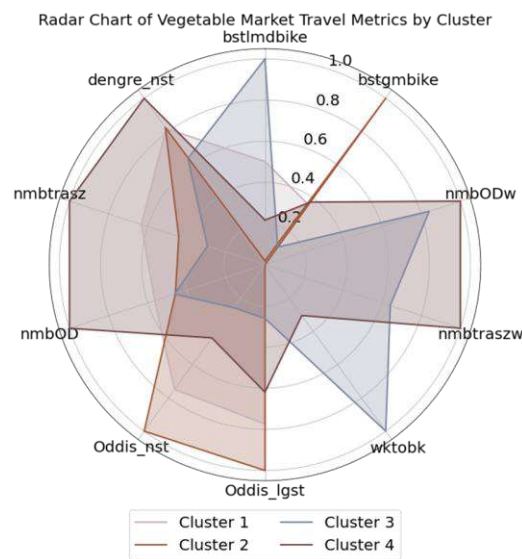


Figure 6.43 Radar diagram of the layout characteristics of four types of living circle vegetable markets

Table 6.19 Summary of vegetable markets layout characteristics across four living circle types

Category	Travel Distance	Vegetable market Quantity and Trip Frequency	Vegetable market Distance Characteristics	Walking Circle Satisfaction	Vegetable market Layout-Travel Pattern	Reasons for Long-Distance Travel	Corresponding Spatial Layout Type of Living Circle
Type ①: “Flat Structure then Balanced Distance” Living Circle	Moderately remote	Limited quantity, higher trip frequency	Moderately remote, sparse distribution	Walking circle none	Mid-to-far distance vegetable market dependency type	Long-distance travel caused by low density	Peri-urban porous type
Type ②: “Neighborhood Absence then Distal Dependency” Living Circle	Farthest	Lowest quantity, relatively few trips	Extremely distant, highly dispersed layout	Walking circle none	Strong dependency on distant peripheral vegetable markets	Long-distance travel due to residential-commercial separation and preference for peripheral vegetable markets	Hollow-core type
Type ③: “Large Nearby-Small Distant then Short-Distance Convenience” Living Circle	Nearest	Relatively low quantity, moderate trip frequency	Proximity-based compact, high-density layout	Extremely high (0.95)	Proximity-based compact convenience type	——	Multi-core type, peri-core hybrid type
Type ④: “Small Nearby-Large Distant then Bypassing Behavior” Living Circle	Moderately medium	Highest quantity, most frequent trips	Medium distance, multi-point layout	Average (0.29)	Dispersed facilities with green accessibility type	Facility layout dispersed but with good green travel environment, moderately acceptable travel distance	TOD type

6.4.3 Commonalities and differences between two-types circles

The Table 6.20 below summarizes the commonalities and differences in the long-distance travel mechanisms between supermarkets and vegetable markets. Both types of facilities exhibit the common feature that **"the maximum size and distance of facilities determine the average travel distance"**. Additionally, the satisfaction with the 15-minute walking circle is an important negative factor for both types of facilities. Supermarket travel is more influenced by the size and distance of the largest facility, with a preference for high-level large supermarkets, reflecting the characteristic of **"medium-to-long-range high-level attraction"**. Vegetable market travel, on the other hand, is more influenced by the distance and quantity of the nearest facilities, with residents being more sensitive to distance, emphasizing **"convenient, multiple points"** layout.

In terms of interaction mechanisms, both facilities show that **"proximity alone is insufficient, and higher-level facilities are still needed,"** but vegetable markets are further constrained by spatial balance and walking environment. Clustering results show that travel patterns in living circles can be categorized into four typical structural types. Supermarket living circles often show a **"along the main road—towards the commercial corridor"** concentration, forming a typical **"hierarchy-driven"** travel pattern, while vegetable markets exhibit a stronger demand for spatial equity. In summary, the planning of both types of facilities should separately strengthen the spatial synergy between high-level supermarkets and balanced, well-distributed vegetable markets.

Table 6.20 Commonalities and differences in long-distance travel mechanisms for supermarkets and vegetable markets

		Commonalities	Differences	
Dimension		Supermarkets and vegetable markets	Supermarkets	Vegetable markets
Impact Mechanisms of Individual Independent Variables	Distance	The average travel distance is determined by the distance to the largest facility and the nearest facility (linear positive correlation)	The largest facility is most important (linear positive correlation)	The distance to the nearest facility is most important (linear positive correlation)
	Distance	Satisfaction within the 15-minute walking circle ranks among the top three in importance (linear negative correlation)	The distance from residential quarters to major commercial corridors holds importance between that of distance and scale (non-linear correlation)	——
	Scale	——	Scale is more important than quantity; the scale of the largest supermarket (linear positive correlation) is more important than the scale of the nearest supermarket (linear negative correlation)	——
	Quantity	——	——	Quantity is more important than scale; the number of vegetable markets (linear positive correlation) is more important than the number of trips to vegetable markets (non-linear correlation)

Table 6.20 Commonalities and differences in long-distance travel mechanisms for supermarkets and vegetable markets (Continued)

		Commonalities	Differences
Interaction Effects of Two Independent Variables	Distance Scale and	Physical proximity alone is insufficient to meet residents' needs; upgrading facility hierarchy and achieving balanced multi-point distribution are key pathways to optimizing travel structures in living circles	When a supermarket is large (e.g., exceeding 600,000 m ²), whether it is the largest or the nearest supermarket within the living circle, it significantly attracts trips within a 2,000-meter range. Only when facilities, whether the largest or the nearest, reach a certain hierarchy can they effectively reduce travel distance
			When the nearest vegetable market is beyond 2,000 meters, travel distance increases significantly, especially if the largest vegetable market is also distant. Even when the distance to a vegetable market is under 1,000 meters, long-distance travel may still occur if satisfaction is below 0.3
Clustering Types of Ten Independent Variables	Distance, Scale, Quantity, Road Conditions, Attitude	Type ①: "Large Nearby-Small Distant then Short-Distance Convenience" Living Circle; Type ②: "Small Nearby-Large Distant then Bypassing Behavior" Living Circle; Type ③: "Flat Structure then Balanced Distance" Living Circle; Type ④: "Neighborhood Absence then Distal Dependency" Living Circle	Supermarket living circles exhibit a structural characteristic of "clustering along arterial roads and converging toward corridors." Long-distance travel often results from high facility hierarchy coupled with remoteness or residential-commercial separation. Trips tend to target mid-to-distal high-level malls, forming types such as "Large Nearby, Small Distant, Short-Distance Convenience" and "Large Distant, Small Nearby, Bypassing Behavior"
			Vegetable market living circles are more influenced by "neighborhood accessibility" and "balanced facility density." Long-distance travel is often caused by facility scarcity and dispersed distribution, highlighting reliance on proximity and multi-point distribution, reflecting planning orientations toward service equity and spatial fairness

6.5 Validation

In the summary above, the conclusion that "the maximum scale - the closest facility distance determines the average travel distance" has high value, mainly reflected in three aspects: firstly, it has universality and is applicable to various types of facility travel behaviors, revealing common mechanisms; Secondly, it has strong operability and can provide a "dual threshold" design strategy for facility layout; The third is to balance fairness and efficiency, with spatial proximity and facility level orientation, and has the potential to be transformed into urban spatial policies and standards. Therefore, in response to this conclusion, the study validated it by drawing a shopping travel space scale distance structure model (travel structure method).

Taking the 15-minute service area of No.22 supermarket in northern Tangshan as an example (Figure 6.44), this study reveals the facility layout and travel distance characteristics of four representative residential quarters, and verifies that the maximum scale facility and the nearest facility distance determine the average travel distance. There are a total of 7 supermarkets in this area, with a radius of about 3km. There is 1 high-level supermarket, which is the 22nd supermarket, 2 medium level supermarkets, and 4 low-level supermarkets.

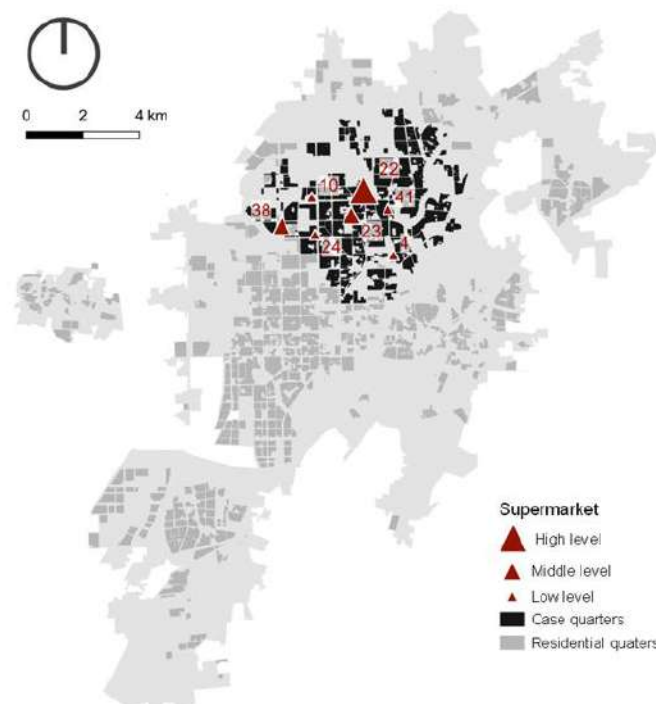


Figure 6.44 Case: 15 minute service area of No.22 supermarket in northern Tangshan

Table 6.21 Supermarket number, building area, and grade

shchID	building area (m2)	level	level_ID
4	6769.46	low	L4
41	12000.00	low	L3
10	20382.43	low	L1
24	25000.00	low	L2
23	32664.95	middle	M2
38	32912.73	middle	M1
22	866245.31	high	H

According to the theory of living circle, the ideal layout and travel of this area should be as follows: the 22nd service area of the supermarket fully covers two intermediate level supermarket service areas, and each intermediate level supermarket service area fully covers two low-level supermarket service areas. The travel to obtain supermarket services should be to go to the various levels of supermarkets (i.e. the various levels of life centers in the theory of living circle) to which one belongs for each residential quarter. For example, one of the residential quarters in the L1 supermarket service circle most often goes to L1, followed by M1, and occasionally goes to H. This residential quarter will not go to L2, L3, L4, or M2 (where L refers to Low, M refers to Middle, and H refers to High).

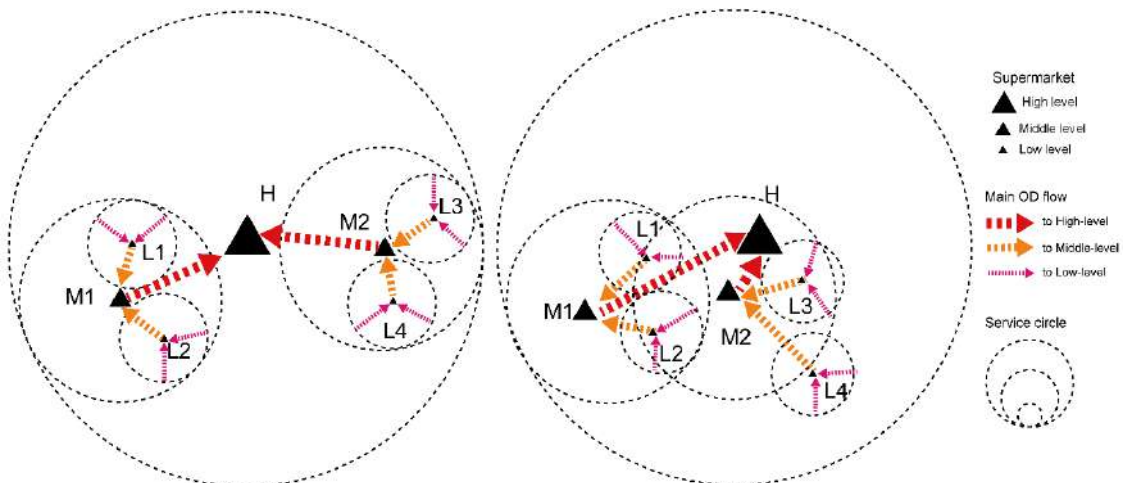


Figure 6.45 Ideal layout and travel, and real layout and travel results

However, in reality, the layout of supermarkets is unbalanced, with two intermediate supermarkets M1 and M2 clustered near the center of Tangshan - on the south side of the H supermarket service area, resulting in a facility depression on the north side and a

compact travel structure on the south side. Moreover, based on the real residential quarters of M1 and M2 supermarkets - supermarket OD travel flow clusters, there is a "power competition zone" between the two supermarkets, where the residential quarters within these "competition zones" go to both M1 and M2.

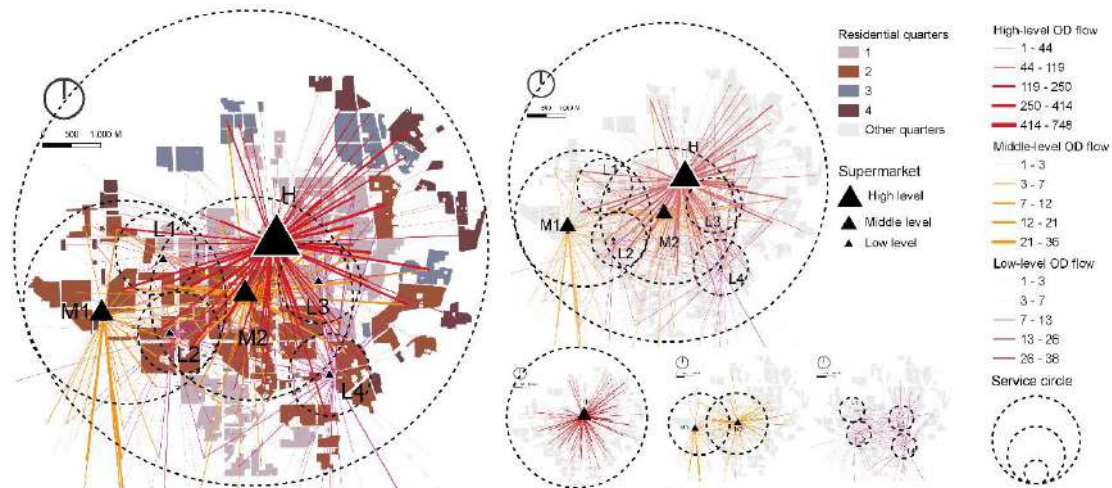


Figure 6.46 Residential quarter-supermarket travel flow cluster

(service circle radius determined based on the average cumulative passenger flow
radius of about 40%)

The traditional floor plans and travel structure diagrams of the four types of residential quarters are as follows. The first type (i.e. convenience type) residential quarter is located around the H supermarket, which is the best area in this district. Taking one of the representative residential quarters as an example, from near to far, it leads to H, M2, and L3 respectively, and the travel structure presents an inverted triangle shape, with a ratio of 1:1:1 for the number of supermarkets.

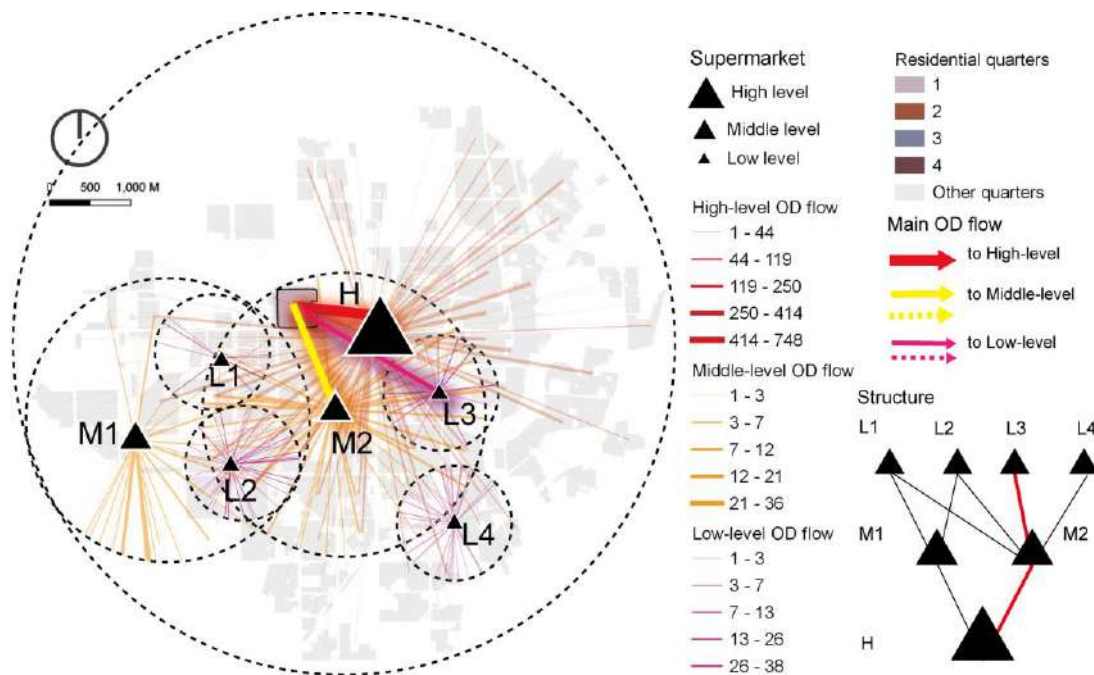


Figure 6.47 Residential quarter-supermarket travel flow cluster and travel structure of representative cases of the first type of residential quarter

Table 6.22 Statistics of the number of clusters and trips between residential quarters and supermarkets for representative cases of various residential quarters

	low				middle		high	ratio of supermarket (low: middle: high)	ratio of trips (low: middle: high)
cluster/shch ID	4 (L4)	41 (L3)	10 (L1)	24 (L2)	23 (M2)	38 (M1)	22 (H)		
1	0	2	0	0	21	0	297	1:1:1	2:21:297
2	0	0	9	3	10	10	215	2:2:1	12:20:215
3	0	2	0	0	2	0	34	1:1:1	2:2:34
4	0	1	0	0	0	0	275	1:0:1	1:0:275

The second type of residential quarter (near, small, and distant) is located in an area closer to H. The solid red line in the figure indicates that the residential quarter travels to the affiliated facility (the number of people visiting this facility is the largest among facilities of the same level), which is the facility closest to the residential quarter under this level of facilities. The dotted red line indicates that the residential quarter travels to the non-affiliated facility, which is the facility slightly farther away from the residential quarter under this level of facilities. The residents of the case residential quarter in L1

service area go to H, M1, and L1 respectively. Interestingly, in addition to M1, they also go to the same level of M2, because M2 is a supermarket under the Tangshan old brand department store group. Based on the semantic quality evaluation results of Dianping, M2 has higher quality than M1 (no evaluation). Among the 13 dimensions, M2 is superior in 7 dimensions, inferior in 3 dimensions, and moderate in 3 dimensions. Therefore, even if M2 is farther away, the residential quarter will still choose to go further than M1 to M2. In addition to L1, they also go to L2 of the same level, but L1 is the main one. Because L1 is close and of high quality (10 out of 13 dimensions are excellent and 3 are poor), while L2 is far away and of slightly lower quality than L1 (9 out of 13 dimensions are excellent and 1 is poor) (Figure 6.48).

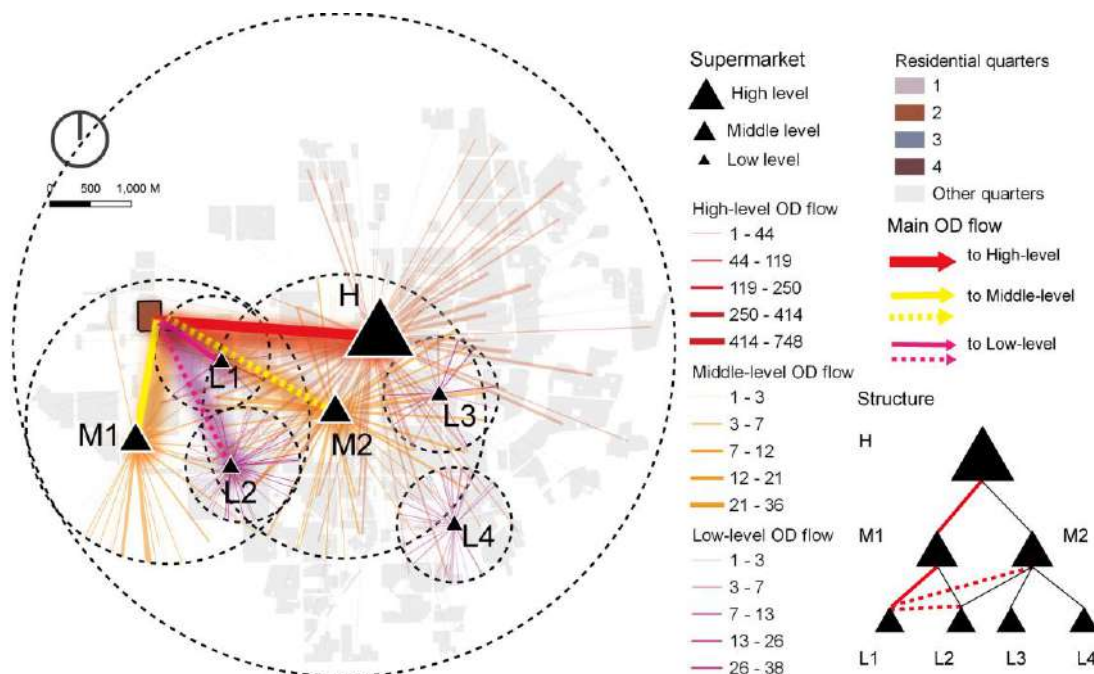


Figure 6.48 Residential quarter-supermarket travel flow clusters and travel structures of representative cases in the second type of residential quarters

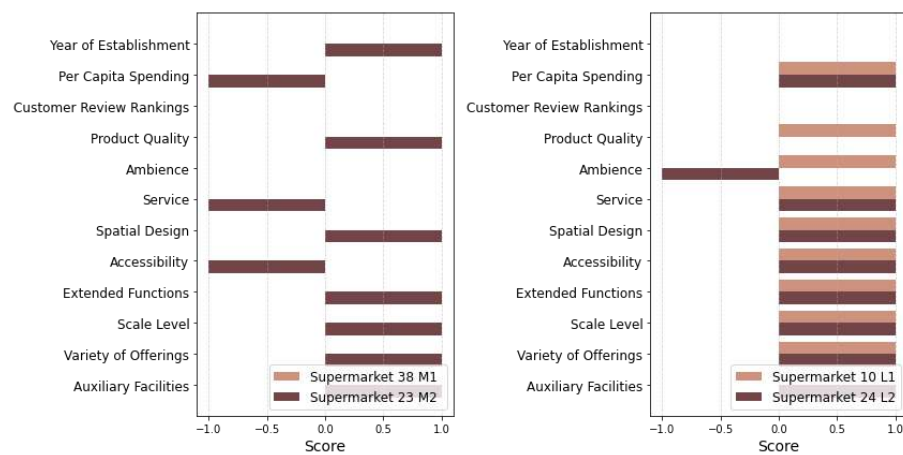


Figure 6.49 Comparison of quality between Supermarket M1 and M2 (left) and comparison of quality between L1 and L2 (right)

The third type (flat structure and balanced distance) residential quarter is located on the north side of the area, far from the supermarket cluster. The destinations of the case residential quarter are H, M2, and L3, roughly equidistant from the three supermarkets, with a ratio of 1:1:1 for the number of supermarkets at each level.

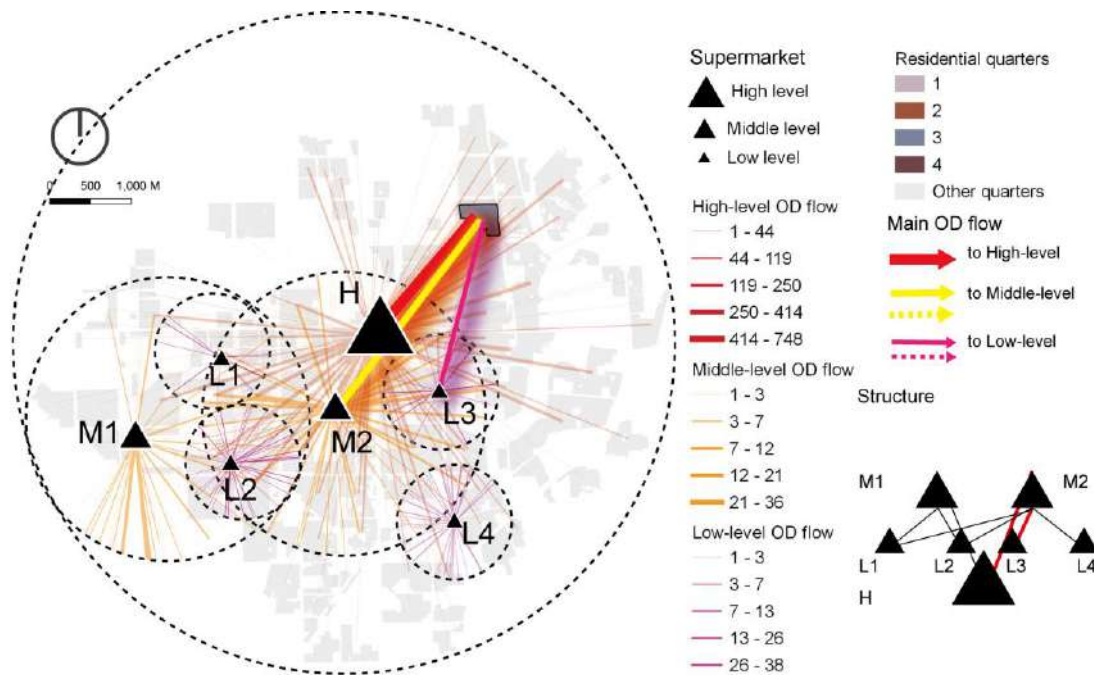


Figure 6.50 Residential quarter-supermarket travel flow cluster and travel structure of representative cases of the third type of residential quarter

The fourth type (neighborhood lacking remote dependence) of residential quarters is located on the northernmost side, farthest from the supermarket cluster, with only

destinations H and L3, and abandoning the M2 destination due to its long distance and lack of attractiveness.

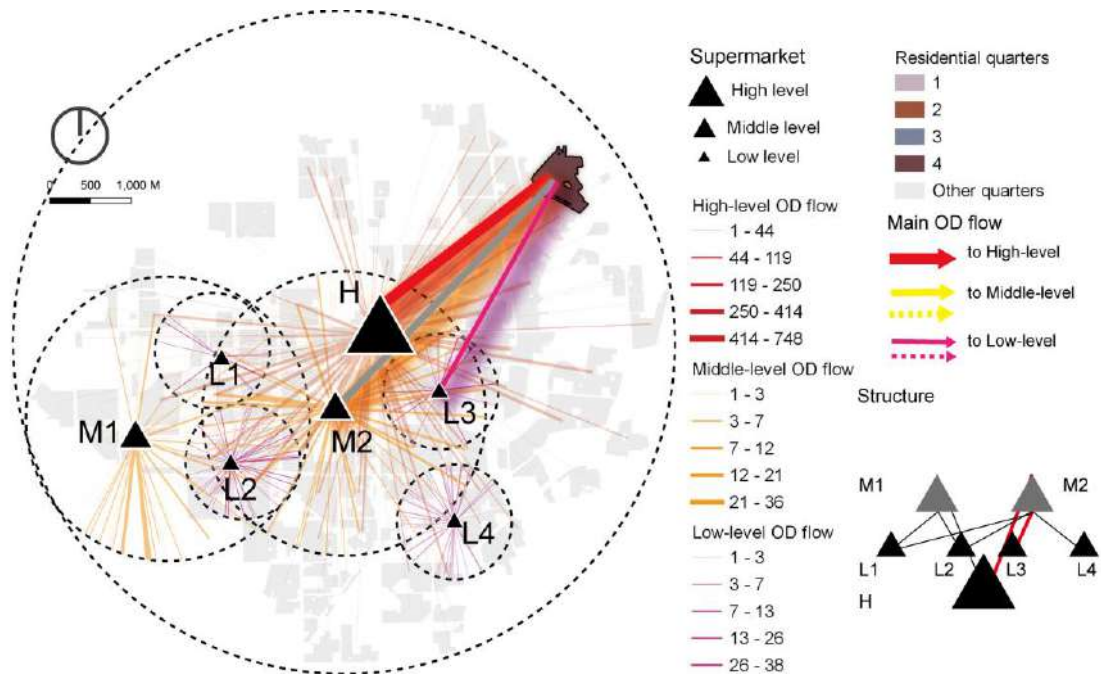


Figure 6.51 Residential quarter-supermarket travel flow cluster and travel structure of representative cases of the fourth type of residential quarter

From the above, it can be found that:

Firstly, these four residential quarters are all the largest supermarkets with the highest number of trips;

Secondly, these four residential quarters are dominated by the maximum supermarket travel distance, with the nearest supermarket assisting and jointly determining the average travel distance.

Therefore, it has been verified that the maximum distance between facilities and the nearest facility have a decisive impact on the average travel distance. Moreover, based on the layout and travel characteristics of this area, it can be inferred that in other urban areas, the scarcity of large-scale facilities and the absence of small-scale neighborhood facilities will inevitably lead to some residential quarters having shorter average travel distances and some residential quarters having longer average travel distances. Due to the fact that supermarket travel can fully prove the viewpoint, the study omitted the verification of the vegetable market.

6.6 Summary

Based on a sample of 533 supermarkets and 357 vegetable markets, this chapter uses the XGBoost regression model, SHAP interpretability analysis, hierarchical clustering method, and travel structure diagram quadruple path to reveal the deep mechanism of the layout of single-type facilities in the living circle and travel distance during the destination selection stage, thereby providing support for avoiding long-distance travel for single-type facilities and shortening the average travel distance through layout optimization. The study found that:

(1) Facility scale and the phenomenon of choosing distance over proximity

For a certain type of facility with multiple destinations within a living circle, scale (building area) plays a decisive role in residents' travel choices. About 50% of residents travel to vegetable markets, and over 70% of residents travel to supermarkets, with supermarkets averaging over 1 km longer, reflecting a significant preference for large-scale facilities. Comparing the factors affecting the closest and most frequently visited facilities, supermarkets are mainly driven by scale, variety, and spatial environment, while vegetable markets are more dependent on scale and functional expansion. Scale is highly correlated with other facility characteristics and has been verified in the visualization of long-distance travel flows to large-scale facilities and the high-fitting Hough model. Therefore, it is confirmed to be a representative of the comprehensive characteristics of facilities and is included in subsequent analysis as independent variables. The distance to the largest facility and the distance to the nearest facility in the living circle jointly determine the average travel distance. The regression clustering and verification results show that in the layout of single-category facilities in the living circle, high-level facilities structurally dominate long-distance travel, while medium and low-level facilities functionally undertake daily nearby services. The two together constitute a hierarchical service system within the 15-minute cycling circle.

(2) The distance to the largest facility and the distance to the nearest facility jointly determine the average travel distance

Supermarket travel is more attracted to large supermarkets at the far end, showing the characteristics of gathering along the corridor and converging to the corridor, while vegetable markets are more dependent on neighborhood facilities, showing a stronger multi-point space demand. The results of the XGBoost model show that the supermarket travel distance is mainly affected by the largest supermarket and the nearest supermarket.

At the same time, the satisfaction of the walking circle, the number of facilities and corridor accessibility are also important; the vegetable market is more dependent on the nearest facility and is affected by the scale and travel environment. SHAP clarifies the influencing path and action range of the variables. Supermarkets larger than 60,000 square meters and located more than 2 kilometers away still retain significant appeal. However, proximity to vegetable markets is even more crucial, with residents' travel distances significantly increasing when the nearest facility is more than 2 kilometers away.

Based on SHAP value clustering, both types of facilities form four types of lifestyle circles: “Large nearby-small distant then short-distance convenience” living circle; “Small nearby-large distant then bypassing behavior” living circle; “Flat structure then balanced distance” living circle; “Neighborhood absence then distal dependency” living circle. These are distributed, in descending order, around large facilities such as traditional city centers, near secondary centers, near peripheral arterial roads, and finally in new urban areas or suburbs. The “Large nearby-small distant then short-distance convenience” living circle boasts optimal city center resources, with a high number of facilities and the largest facilities located close by, resulting in extremely short travel distances (1.5 kilometers for a supermarket and 0.8 kilometers for a vegetable market). The “Small nearby-large distant then bypassing behavior” living circle is the second most common, often bypassing nearby facilities in favor of distant city center supermarkets and vegetable markets. The “Flat structure then balanced distance” living circle has a low facility density, balanced facility scales, and close and moderate travel distances. The “Neighborhood absence then distal dependency” living circle faces a prominent problem of residential and commercial space fragmentation. Supermarkets and vegetable markets are extremely rare and located far away, resulting in the longest travel distances (2.9 kilometers for a supermarket and vegetable market).

The core finding of this chapter is that it offers a scale-distance coupled analysis for facility short-distance-oriented spatial structure renewal, including the 15-minute cycling living circle short-distance planning threshold and short-distance 15-minute cycling living circle samples. This chapter reveals the role of facility scale and hierarchical effects in long-distance travel, complementing Chapters 4 and 5.

CHAPTER 7 FINDINGS AND PROPOSALS: FACILITY LAYOUT FOR GREEN TRAVEL IN 15-MINUTE CYCLING LIVING CIRCLES

Based on the correlation research in the previous three chapters, this chapter compares, sorts out and integrates the conclusions of the three studies, reiterates the key conclusions and extracts cross-research inspirations, and based on this, proposes a green travel-oriented living circle facility layout update strategy.

7.1 Empirical findings of key facility layout patterns for green-travel living circles

Based on the variable importance ranking, trend characterization, and sample classification results from multi-model regression and clustering in Chapters 4 to 6, Section 7.1 identifies the facility layout and street design features of the 15-minute cycling living circle that are significantly associated with green travel, providing direct support for the planning strategies in Section 7.2.

7.1.1 Three core dimensions for three goals of all-type, single-type green travel and single-type destination choice

Among the six interactive dimensions of green travel, accessibility, density, and road condition are the most core, collectively explaining approximately 88.245% of the overall variance. These dimensions influence behavior at different stages and through different mechanisms: For all-type facilities green travel, accessibility (46.4%) and density (33.3%) jointly explain 79.7% of the variance. For green travel involving only one type of facility, road condition (65%) and accessibility (27.125%) contribute the most, while long-distance travel choices involving only one type of facility are primarily influenced by accessibility (69.64%), density (16.985%), and scale (6.5%) (Table 7.1).

Specifically:

- Accessibility determines travel destinations and green travel mode choices and is a threshold variable for green travel. Markets, supermarkets, express delivery services, pharmacies, and health service points are located within 150-460 meters of residential

quarters, while primary and middle schools are located within 1059 and 378 meters. This living area demonstrates a high degree of green travel. The willingness to travel green for various types of facilities generally begins to decline within 1.2-2.3 kilometers. Despite the trend of preferring distance over proximity, facility travel distance is largely determined by the nearest facility, and trips to markets are more significantly influenced by the distance to the nearest neighborhood facility than to supermarkets.

- Density influences the green travel proportion of all-type facilities, exhibiting a clear threshold effect among 9 type of facilities. For example, markets (7.7-14.9/km²), express delivery services (11.6/km²), and community businesses (6.4/km²) represent the threshold for green travel planning, while an over-concentration of gyms, pharmacies, and other facilities can lead to "facility fatigue."

In terms of travel distance for a single facility type, density has a greater impact on vegetable markets than supermarkets. Among the top ten indicators, four are density-related, while two are density-related. For both supermarkets and vegetable markets, the impact of the number of malls and vegetable markets within a 15-minute bike ride (nmbOD) on average trip distance is nonlinear; either a high or low value can result in long trips.

Density exhibits a threshold effect for both all types of green travel and the distance traveled for a single facility. The median value exhibits the best promoting effect. This is because high density leads to a rich supply of facilities, but these facilities are farther from residential quarters. This, in turn, leads to longer trips during destination selection, ultimately reducing the degree of green travel.

- Road condition primarily plays a role in the green travel mode selection phase. Street design and density factors, such as street length, aspect ratio, spatial integration, and the density of leisure facilities, influence green travel choices for single-type facilities, such as primary schools and supermarkets.

- Attitude primarily determines the priority of basic service configuration. Communities with modular systems and "village-to-community" models should be given priority. Attitudes and instrumental factors have limited influence, but they can serve as social guidance mechanisms to curb long-distance travel.

CHAPTER 7 FINDINGS AND PROPOSALS: FACILITY LAYOUT FOR GREEN TRAVEL IN 15-MINUTE CYCLING LIVING CIRCLES

Table 7.1 Six dimensions and their effect on three dependent variables

Dimension	All-type facility green travel (%)	Single-type facility green travel (%)	Single-type facility long-distance travel (%)	Percentage total (%)
Attitude	4.2	—	7.8 75	6.195 18.27
Density	33.3		0	16.985 50.285
Scale	3.8		0	0 10.3
Diversity	6.8		0	0 6.8
Accessibil ity	46.4	—	27. 125	69.64 143.165
Road condition	5.6	Road conditions total	65	0.685 71.285
		Road conditions- design	42. 75	0
		Road conditions- density	20. 875	0
		Road conditions- diversity	1.3 75	0
Percentage total (%)	100		100	100 300

In contrast, while scale, diversity, and attitude are not dominant, they do provide structural support and regulate behavior under specific conditions:

- Scale plays a role in the facility destination selection phase. Supermarket trips are more driven by size, comprehensive functionality, and spatial environment, while vegetable markets are primarily determined by size and extended functionality, with service quality being a less significant factor. Supermarket trips are characterized by a "distant attraction" model, where large-scale facilities are highly attractive, while vegetable market trips are characterized by a "near-end dependence" model, where proximity is prioritized.

- Diversity: Divergence of the 14 types of facilities within a 15-minute cycling circle is most important, with the strongest promoting effect occurring at a moderate level (divergence $14 \approx 1.4$ -1.6).

In summary, accessibility, road condition, and density constitute the dual core levers for optimizing green mobility. Scale provides structural support, while attitude and diversity complement behavioral and scenario-based adjustments, forming a multi-dimensional driving system from attitude to behavior. Optimization strategies should ensure a high-density distribution of core facilities while balancing accessibility, road condition improvements, and scale grading, forming a comprehensive optimization path with a rational structure and balanced functions.

7.1.2 All-type green travel: different importances and driving mechanism of different facilities

7.1.2.1 Different importances of different facilities

The all-category green travel model in Chapter 5 shows significant differences in the importance of different facility types. Among the 14 subcategories of facilities, vegetable markets and primary schools contribute most to green travel, ranking first (0.066) and second (0.056) in overall importance, respectively. Further analysis reveals that in the accessibility dimension, primary schools have the greatest impact ($\text{prima\_min} = 0.0423$); in the density dimension, vegetable markets are the most prominent ($\text{vegdenw} = 0.0445$). This indicates that these two types of facilities are not only frequently present in residents' daily activities, but also significantly increase travel distances when absent or poorly located, thereby reducing the proportion of green trips.

Among the four major categories of facilities, shopping facilities contribute the most to green travel, with an overall importance of 0.207, with accessibility (0.094) and density (0.113), both ranking first. Educational facilities follow closely behind (0.128), closely followed by health facilities (0.124). Leisure facilities have the smallest overall contribution, at only 0.100. Looking solely at density, the ranking is: shopping (0.113) > health (0.061) > leisure (0.057) > education (0.040).

This difference is highly consistent with the current density of facilities. Current kernel density results show: shopping ($3314.7/\text{km}^2$) > health ($243.3/\text{km}^2$) > leisure ($144.7/\text{km}^2$) > education ($30.2/\text{km}^2$), which is largely consistent with the aforementioned importance ranking. Among these, the density of vegetable markets alone is $12.34/\text{km}^2$, again ranking first among the 14 types of facilities. In terms of distribution pattern, shopping facilities are small and dense, often distributed linearly or in planar patterns

along streets; educational facilities are large and low-density, primarily distributed in a point-like pattern; and health and leisure facilities are of medium density and often clustered. This leads to disparities in supply and also explains the differences in importance. Further analysis of demand reveals that residents' demand for shopping-focused vegetable markets far outweighs their demand for leisure and cultural activity centers. Even with higher supply density, vegetable markets were frequently mentioned, reflecting their daily necessity and high frequency of travel. This result suggests that planners should distinguish between essential and optional facilities, prioritizing essential facilities within resource-limited conditions to achieve a more effective policy outcome.

7.1.2.2 Different driving mechanism of different facilities

In addition to differences in importance, the driving mechanisms of different facility types in terms of density and accessibility also differ significantly. Model results from Chapter 5 show that while education, commerce, healthcare, and leisure facilities are all related to green travel, their key driving dimensions differ. Educational facilities (middle schools, elementary schools, and kindergartens) rely more heavily on high accessibility (0.088, higher than density (0.040)). Shopping facilities (supermarkets, markets, express delivery services, restaurants, and community businesses) and health facilities (pharmacy, clinic, and gym) exhibit dual driving factors. For shopping, accessibility (0.094) and density (0.113) are nearly equal, while for health facilities, accessibility (0.064) and density (0.061) are also roughly equivalent. Leisure facilities (parks, plazas, scenic spots, cultural activity centers, and community service centers) are primarily driven by density (0.057, higher than accessibility (0.043)).

This difference is closely related to the spatial pattern of facilities and residents' travel patterns. Taking educational facilities as an example, their density is far lower than other types: the median density of primary and junior high schools within a 15-minute walking circle of the sample is less than 1/km², resulting in most residential quarters having only one or two schools. One school is sufficient, while additional density has little effect, residents do not need two schools. In this case, increasing facility density does not significantly change residents' commuting options, so green travel primarily depends on accessibility to the nearest facility. Leisure facilities, on the other hand, present a different pattern. While their average density is moderate (cmsvcdenw = 4.49/km², cultudenw = 0.59/km², parkdenw = 0.49/km²), they offer a rich variety of types,

diverse purposes, and high flexibility. A high-density layout significantly increases residents' choice and frequency of use, thereby increasing the likelihood of green travel. Overall, the driving force behind green travel for different types of facilities is influenced by three factors: the spatial distribution of the facilities, the frequency of use by residents, and the elasticity of substitution for travel destinations. If a particular type of facility exhibits a high density, high frequency of use, and strong substitutability, its density has a more pronounced impact on green travel.

7.1.3 Single-type destination and green travel choices: beyond accessibility—roles of facility scale, street design, and density

7.1.3.1 Two roles that accessibility plays in both two choice stages

Facility accessibility impacts the entire travel process and is a rare dimension that plays a dominant role in both stages. Planning must prioritize this high priority. During the facility destination selection phase, some residential quarters prioritize proximity, and the average travel distance to facilities within their living circle is largely determined by the nearest facility. This is particularly true for trips to the vegetable market, where distance to the nearest vegetable market ranks first in terms of average travel distance, while distance to supermarkets ranks second. The high importance of satisfaction within the 15-minute walking circle for both types of facilities (0.2561 for vegetable markets and 0.1372 for supermarkets, both close to the importance of distance to the nearest facility) also demonstrates the significant impact of proximity on travel.

During the facility green travel mode selection phase, the willingness to travel green for various types of facilities generally begins to decline within a range of 1.2-2.3 kilometers. Regarding different types of facilities, health and leisure facilities have longer walking and cycling distance thresholds than other types. Supermarkets have longer walking and cycling distance thresholds than community commercial outlets.

However, accessibility does not guarantee green travel; accessibility plays a synergistic role with other dimensions, primarily scale and road conditions. Large-scale nearby facilities are conducive to residents choosing nearby facilities during the destination selection phase, resulting in shorter average travel distances overall. Good road conditions leading to nearby facilities are conducive to residents choosing green travel modes during the green travel mode selection phase. For detailed analysis, please

see Sections 7.1.3.2 and 7.1.3.2.

7.1.3.2 Facility scale affects travel destination choice

Facility scale is a core mechanism influencing travel distance choices, with the distance between the nearest and largest facilities jointly determining trip distance. Chapter 6, based on an analysis of trips to supermarkets and markets, found that the distance to the nearest facility and the distance to the largest facility ranked in the top three among all facility layout variables. The bivariate structure of "distance from the nearest facility to the largest facility" within a 15-minute cycling circle jointly determined residents' actual travel distances. In most cases, residents consider both the convenience of the nearest facility within the circle and the overall attractiveness of the larger facilities within the circle. When the largest facility boasts significant advantages in terms of size, service type, or environment, residents tend to travel further, even if the distance is greater.

For supermarkets, distances exceeding 1981 meters (largest)/1607 meters (nearest) significantly increase trip lengths. A walking circle satisfaction score below 0.19 also increases distance, confirming the "proximity" threshold. Furthermore, residents travel across their living circles for large, well-serviced supermarkets, particularly when the largest supermarket exceeds 60,000 square meters and is more than 2,000 meters away. If the nearest supermarket is small or unevenly distributed, its effect on curbing long-distance travel is limited. For vegetable markets, travel is more influenced by the distance and number of the nearest neighborhood facilities, emphasizing a "near, convenient, and multiple" layout. When the distance to the nearest vegetable market exceeds 2,000 meters, travel distance increases significantly, especially when the largest vegetable market is also far away. When the distance to the vegetable market is less than 1,000 meters but the satisfaction level is below 0.3, long-distance travel is still possible.

Both supermarket and vegetable market living circles exhibit four types of travel structures: Type ①: "Large Nearby-Small Distant then Short-Distance Convenience" Living Circle; Type ②: "Small Nearby-Large Distant then Bypassing Behavior" Living Circle; Type ③: "Flat Structure then Balanced Distance" Living Circle and Type ④: "Neighborhood Absence then Distal Dependency" Living Circle ". In these structures, the nearest facility is typically smaller and closer than the largest facility, consistent with the central place theory and the living circle theory's nested hierarchy of large, medium, and small, with large facilities being fewer and more distant than small

ones.

In summary, this bivariate structure determines distance patterns that vary among different functional facilities, but the universality and stability of the scale factor provides a direct basis for hierarchical layout.

7.1.3.3 Street design and density affect green travel mode choice

In the single-facility green travel phase, in addition to travel distance, street design and density are the primary influencing factors for all-type facilities green travel. The single-facility green travel model in Chapter 5 found that two road condition dimensions and variables—street design (street segment length, street wall continuity, street aspect ratio, and integration) and street density (residential building volume ratio, etc.)—recurred among the green travel influencing variables for all-type facilities travel and significantly influenced travel mode choice. Design dimension variables had the highest frequency and significant impact (e.g., topographic relief, street segment length, and bike lanes), demonstrating the crucial role of the street microenvironment in shaping travel intentions. Density provides structural support in terms of functional configuration and population carrying capacity.

In terms of the green travel-promoting characteristics of these street variables, road condition design variables are mostly "median-promoting." For example, for supermarkets, the street height-to-width ratio (*heitwidmea*) is an influencing factor, with the range (0.4-0.5) being suitable for walking and cycling. Road condition density variables generally exhibit a threshold effect. For elementary schools, the residential building volume ratio (*Drebd*) (0.8–1.18) provides support for green travel. These variables can be divided into three categories: Category A factors share common influencing mechanisms, meaning they exhibit similar trends or roughly consistent promotional ranges for the green travel ratios of various types of facilities. Typical examples include main road length and street wall continuity. Category B factors share different influencing mechanisms, meaning they exhibit different correlations or promotional ranges, such as greening ratio (*ndvi_mean*) and non-residential building density (*D_no_re_bd*). Category C variables are sensitive variables specific to a particular type of facility, such as enjoying facility density (*DLEISURE*) and caring facility density (*DHEALTH*). Category A and C factors possess universal green travel thresholds and are highly transferable. Urban planning and design should prioritize ensuring these key

factors reach appropriate ranges.

Based on the key Category A and C variables in the street design and density dimensions, cluster analysis identified four street types, demonstrating significant spatial heterogeneity. "Multi-dimensional promotion" streets boast mixed functions, superior building strength, and continuity, and are the strongest supporters of green travel. "Length-dominated" streets, while length-based, are conducive to green travel, but lack a single spatial and functional configuration. "Enclosed leisure" streets rely on a high sense of enclosure and a concentration of leisure facilities to create potential appeal. "Support-deficient" streets, characterized by low design and density, reflect a loose structure and insufficient functionality, and are in urgent need of intervention. These street types exhibit distinct geographic clustering and are closely related to the stage of urban renewal and their functional positioning, providing a categorized basis for green travel optimization strategies centered on street design and density.

This conclusion suggests that optimizing facility layout must be combined with improving street spatial quality; simply increasing the number of facilities is insufficient to steadily increase the proportion of green travel.

7.1.4 Low green travel living circles with low accessibility and low density

Mid-to-high density and high accessibility are the primary spatial characteristics of high green travel living circles, while low density and low accessibility are the primary spatial characteristics of low green travel living circles. The all-facility green travel model and clustering results in Chapter 4 show that the facility density and accessibility of the three types of low green travel living circles near townships—porous, hollow, and fan-shaped—are significantly below average. All 14 types of facilities exhibit low levels of accessibility, with numerous slow-moving traffic interruptions and an unbalanced functional structure. Taking vegetable markets as an example, the density (vegdenw) and accessibility (vegmin) of the three low green travel living circles are 12.36, 8.25, and 16.52 per square kilometer, respectively, and are within a walking distance of 4.15, 6.03, and 3.29 minutes, respectively. These low-quality living circles perform extremely poorly in highly important and consistently positively impactful facilities and dimensions, such as the density of vegetable markets, primary schools, supermarkets, community service centers, and express delivery facilities, as well as the accessibility of primary schools, supermarkets, community businesses, express delivery, health facilities, pharmacies, and

parks. For example, the mean SHAP values for primary school accessibility in the three low-green travel living zones were -0.006, -0.002, and -0.004, respectively, indicating that primary school accessibility falls outside the green travel promotion range.

This is because these low living circles are often located on the city fringes, in newly built areas, or in single-use areas, characterized by low population and building density, few downtown nodes, and poorly accessible and small-scale facilities. This results in a staged explanation: during destination selection, residents choose facilities farther from the city center for better services, resulting in longer travel distances. For example, in Chapter 6 Validation, four representative residential quarters in northern Tangshan preferred to travel further to the largest municipal supermarket in their area for shopping, rather than relying solely on nearby smaller malls. This resulted in shopping trips being doubled. During the green travel mode selection phase, residents endured both longer travel distances and poor road conditions, particularly street design and density, leading them to choose non-green travel modes. For example, in Chapter 5, many supermarket travel clusters in Tangshan's suburbs were long (over 1 km) and had low street design and density (outside the green travel promotion range), resulting in a green travel ratio below 0.5. Taking both phases into account, non-green travel accounts for a high proportion of residents' travel within these disadvantaged residential quarters.

For these areas, it is recommended that measures such as adding high-frequency essential facilities, reducing accessibility radius, and improving slow-moving networks be prioritized to break structural travel inertia.

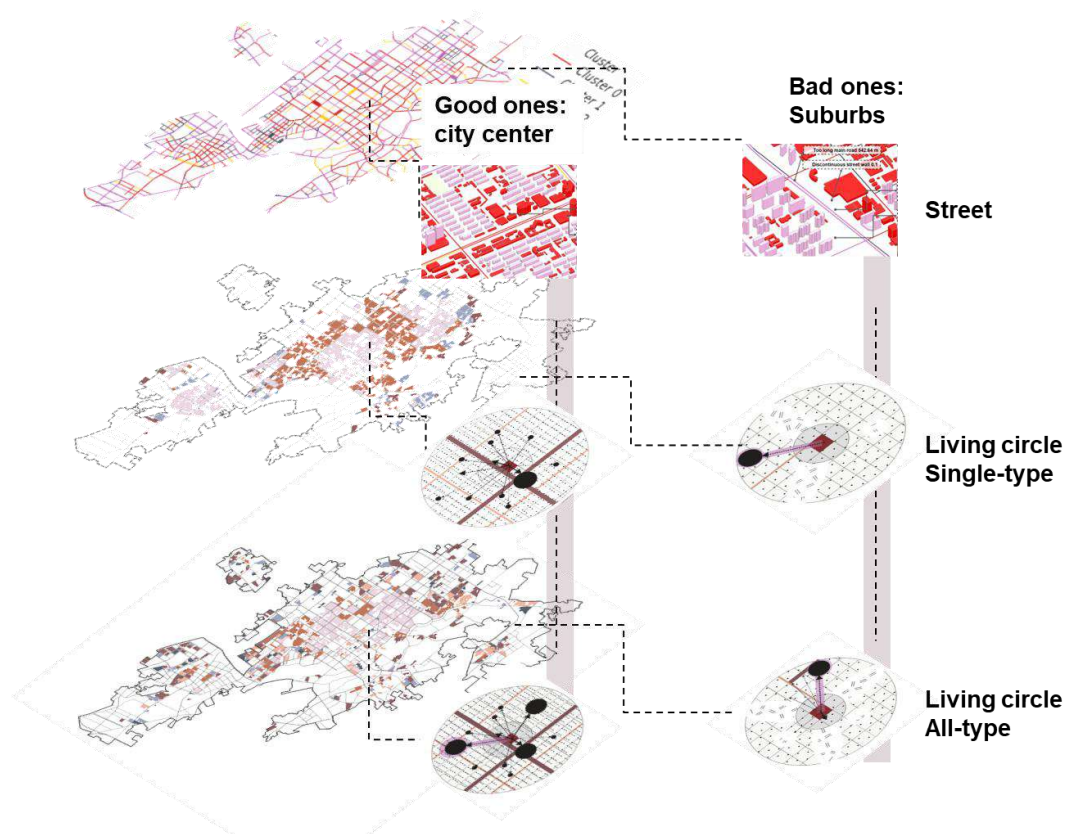


Figure 7.1 Low green travel living circle located in suburbs with bad facility layout in all levels of living spaces

7.2 Green travel-oriented facility layout renewal strategy for living circles

7.2.1 Integrative strategies across six dimensions for all-type and single-type green travel

Before proposing the strategy, the paper briefly reviews the French experience. As the birthplace of the "15-minute city" concept, France's living zone planning emphasizes a hierarchical infrastructure structure, a multi-center layout, and a focus on green mobility (see Section 7.2.2 - 7.2.6 for details). This experience aligns closely with the empirical results from this paper's Tangshan study, validating the rationale of the empirical conclusions and providing international reference and inspiration for the proposed strategy.

Based on empirical evidence and French experience, this paper proposes a green

travel-oriented renewal strategy for 15-minute cycling circles. First, it argues that Tangshan's 15-minute cycling living circle delineation method is not conducive to facility renewal. Living circle planning should be pursued from two perspectives: a "facility-centered" approach and a "residential quarter-centered" approach. Second, it argues that green travel living circles require coordinated advancement along six dimensions, with key breakthroughs in accessibility, road conditions, and density. Specific strategies are proposed based on these six dimensions, and their implementation relies on facility renewal and renovation methods based on spatial differentiation. The realization of green travel-oriented updates in living circles relies on efforts in the three perspectives, and the relationship between these three perspectives is introduced in Figures Figure 7.2 and Section 7.2.1.1-7.2.1.3.

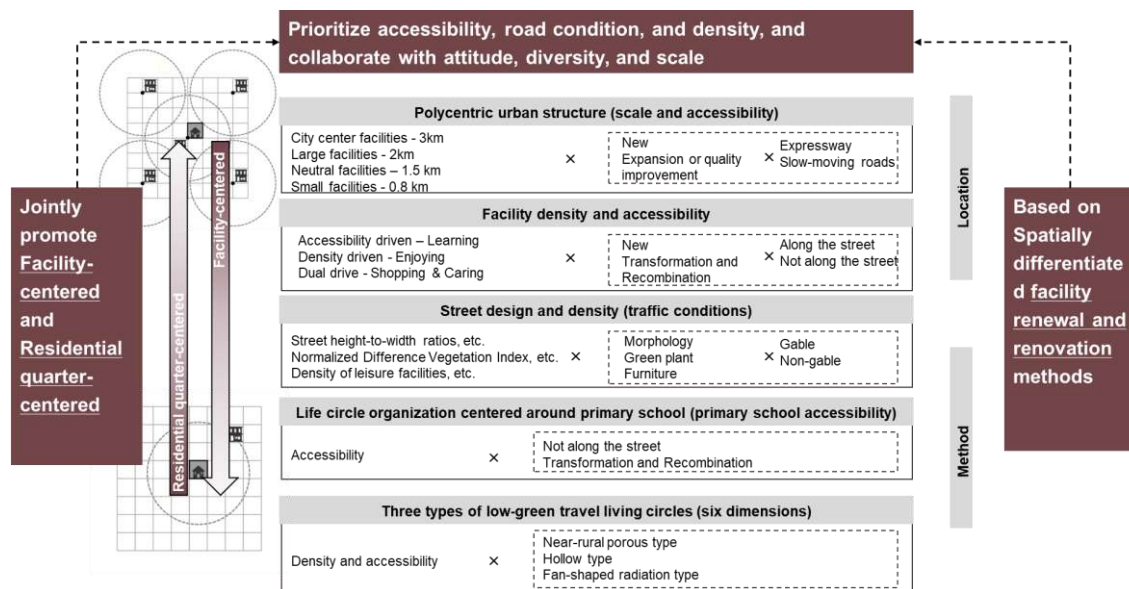


Figure 7.2 Framework of 15- minute cycling living circle green travel-oriented update strategy

Based on the above strategic outline, the logical progression of Sections 7.2.2 through 7.2.4 of this paper follows: First, the paper proposes planning indicators based on correlation analysis, such as a recommended facility density value; Second, to achieve this value, the paper proposes spatially differentiated renewal and renovation methods, such as morphological transformation, planting, and furniture insertion; Finally, the paper introduces the practical experience of Paris, France, the birthplace of the 15-minute city concept, to demonstrate how the paper's empirical findings and strategies were developed

and provide insights for the application of these findings in Tangshan, China. Sections 7.2.5 and 7.2.6, respectively, propose organizational recommendations centered around primary schools and optimization suggestions for three types of low-green travel living zones.

7.2.1.1 Relies on collaborative advancement of “Facility-centered” approach and “Residential-centered” approach

Planning should simultaneously embrace both a "facility-centered" and a "residential quarter-centered" approach. The strategies proposed in this article, including facility structure optimization, density control, accessibility settings, and street environment optimization, originate from a residential-centered approach but are equally applicable to facility-centered layout renewal.

The "facility-centered" approach focuses on optimizing the overall functional structure of the city, primarily involving "facility structure optimization" and "accessibility settings." It uses a facility hierarchy system to optimize functional distribution, achieving a rational combination of large, medium, and small facilities and spatial complementarity. A disadvantage is that it can be difficult to address shortcomings, leading some residents to travel excessively long distances, thereby reducing the proportion of green travel. This is especially true for hollow living areas, where various facilities are often insufficient, making facility-centered renewal challenging. The "residential quarter-centered" approach focuses on precisely meeting residents' daily needs, primarily involving "density control" and "accessibility settings." It targets key facilities within residential living areas, reducing residents' daily travel distances. A disadvantage is the potential for redundant facility layouts and inefficient resource utilization. Both approaches should be promoted in tandem to establish a facility hierarchy system, thereby forming an efficient green travel network that connects the city's functional structure with residents' lives.

7.2.1.2 Relies on accessibility, road conditions, and density for priority breakthroughs, along with collaborative efforts of attitude, diversity, and facility scale regulation

These six dimensions serve as core tools for optimizing the layout of living facilities and guiding green travel. Within the framework of both "facility-centered" and

"residential quarter-centered" approaches, the paper proposes five planning strategies: ① Decentralization of urban structure (scale and accessibility); ② Optimization of facility density and accessibility; ③ Optimization of street design and density (road condition dimension); ④ Organization of living communities centered around primary schools (primary school accessibility); and ⑤ Differentiated optimization of three low-green travel living communities (combining the six dimensions). Strategy 1, Strategies 4, and 5 represent two extreme approaches, with the former leaning more toward "facility-centered" and the latter two closer to "residential-centered." Strategies 2 and 3 combine both approaches, offering dual-perspective applicability.

7.2.1.3 Relies on facility renewal and renovation methods based on spatial differentiation

To achieve these six optimization dimensions, this study further proposes renewal and renovation methods based on the spatial differentiation of facilities. Renewal and renovation methods encompass new construction, expansion, and upgrading, new construction, renovation, and integration, or facility renovation methods such as morphological reconstruction, greenery, and street furniture configuration. For example, within the street design and density optimization strategy, the paper not only reiterates the appropriate range for indicators such as street height-to-width ratios but also proposes optimization pathways through morphological reconstruction, greenery, and street furniture configuration for different scenarios, such as those above or below thresholds, and those with gable or non-gable sides. This translates empirical findings into concrete planning interventions.

7.2.2 Accessibility–scale: polycentric urban structure upon scale and spatial differentiation

Based on the mechanism of the impact of long-distance travel caused by single-type facilities, the paper proposes the construction of a multi-center urban facility network structure with different service radii based on the level of facility scale. Empirical findings show that residents' travel distance is determined by the "largest facility + the nearest facility", so a hierarchical layout is necessary. If large facilities are overly concentrated in a single center, it will lead to long-distance travel across regions, making green travel difficult to guarantee. Therefore, a multi-center structure is the spatial guarantee for a

hierarchical layout, ensuring that different facilities are reasonably matched at the city-district-neighborhood levels. In terms of location, larger urban centers and facilities are more suitable for layout at major central nodes and rapid corridors, while smaller facilities are more suitable for layout at neighborhood nodes and slow-moving environments. From large to small, facilities should be matched with different renewal methods: " New construction, or Expansion and quality improvement" (Table 7.2).

First Category: City Center-Level Facilities

These facilities typically have a service radius of over 3000 meters and serve a city-wide aggregation and radiation function. It is recommended to position these facilities around main city centers and transportation hubs, with a focus on large malls, city-level medical centers, and major sports facilities. These facilities should rely on the main road network and the city-level public transportation system, integrating multi-functional and composite services to meet cross-circle travel demands. They will also encourage middle- and long-distance green travel modes, such as cycling-to-rail transit connections.

Second Category: Large Facilities

With a service radius controlled around 2000 meters, these facilities support multiple districts as high-attraction nodes. It is recommended to place them in urban sub-centers or along main roads and TOD (Transit-Oriented Development) corridors, suitable for the distribution of large malls and regional vegetable markets. Their layout should consider commercial axes and public transportation connection points, creating multi-point distributed service corridors to ensure the radiation function of large facilities to external areas while avoiding excessive concentration in the city center, which could lead to travel polarization.

Third Category: Medium-Sized Facilities

These facilities typically have a service radius of about 1500 meters and mainly provide daily services at the district level. They should be prioritized in sub-center nodes, neighborhood centers, or around community market squares, forming service nodes with multiple functions. Medium-sized facilities like malls, vegetable markets, and clinics can be distributed near public spaces and intersection points to enhance the complexity and frequency of facility use, encouraging commuting walking and cycling within the district.

Fourth Category: Small Facilities

These facilities have a service radius controlled between 800–1000 meters, serving as basic nearby-access facilities. They should be densely distributed within residential

quarters, along pedestrian networks, near bicycle stations, and around neighborhood nodes to enhance local service connectivity. Specifically, vegetable markets, convenience stores, and similar facilities can be integrated into active street areas through embedded layouts or ground-level commercial complexes, creating a surface-level service network that strengthens the end-stage relay mechanism for green travel.

In conclusion, the layout of living circle facilities should match the corresponding urban center structure, transportation network location, and travel mode based on their service levels, forming a "facility level $\times$ spatial location" combination guidance system. It is recommended to incorporate this strategy into detailed urban planning and specialized facility planning as a spatial structure optimization path to guide green travel, facilitating the realization of the "from center to street, from departure to arrival" full-circle transformation goal.

Table 7.2 Multi-center layout suggestion

Hierarchy Category	Recommended Service Radius	Renewal method	Recommended Layout Location
Urban Center (Mega-scale)	≥ 3000 meters (Regional Center)	Expansion and quality improvement	Primary urban hubs, rail transit stations, multimodal transportation hubs
Large-scale Facilities	≤ 2000 meters (Living circle Periphery)	Expansion and quality improvement	Arterial roads, commercial corridors, TOD corridors
Medium-scale Facilities	≤ 1500 meters (District Core)	New construction; Expansion and quality improvement	Secondary urban centers, neighborhood centers, branch road nodes
Small-scale Facilities	≤ 1000 meters (Neighborhood Interior)	New construction	Slow-traffic networks, street nodes, bicycle station proximity

For example, in France, in July 2023, the "20-Minute District" concept was adopted in the Île-de-France region with the release of the **Master Plan for the Environment, SDRIF-E** (Schéma directeur de la région Île-de-France-Europe). Based on the existing centers, the plan proposes the creation of additional centers, resulting in over 100 sub-centers and 27 main centers. This creates a multi-centered structure with mixed functions and collaboration, balancing the distribution of activities across the Greater Paris region.

These main and sub-centers will play a key role in regional organization, promoting

social-economic diversity, and supporting low-carbon and environmentally-friendly development. In Paris, the plan proposes adding more remote working spaces that also provide multifunctional services. These third spaces will allow residents to easily access diverse services, employment, shops, and recreational facilities, enhancing the flexibility and proximity of work and life^[34].

Additionally, to improve mobility, the region is gradually advancing the construction of the **Grand Paris Express**, which includes five new lines and 67 new stations. This will connect the entire region and improve its vitality. The new stations along these lines will support high-density service hubs, facilitating residents' proximity-based mobility (Figure 7.3).

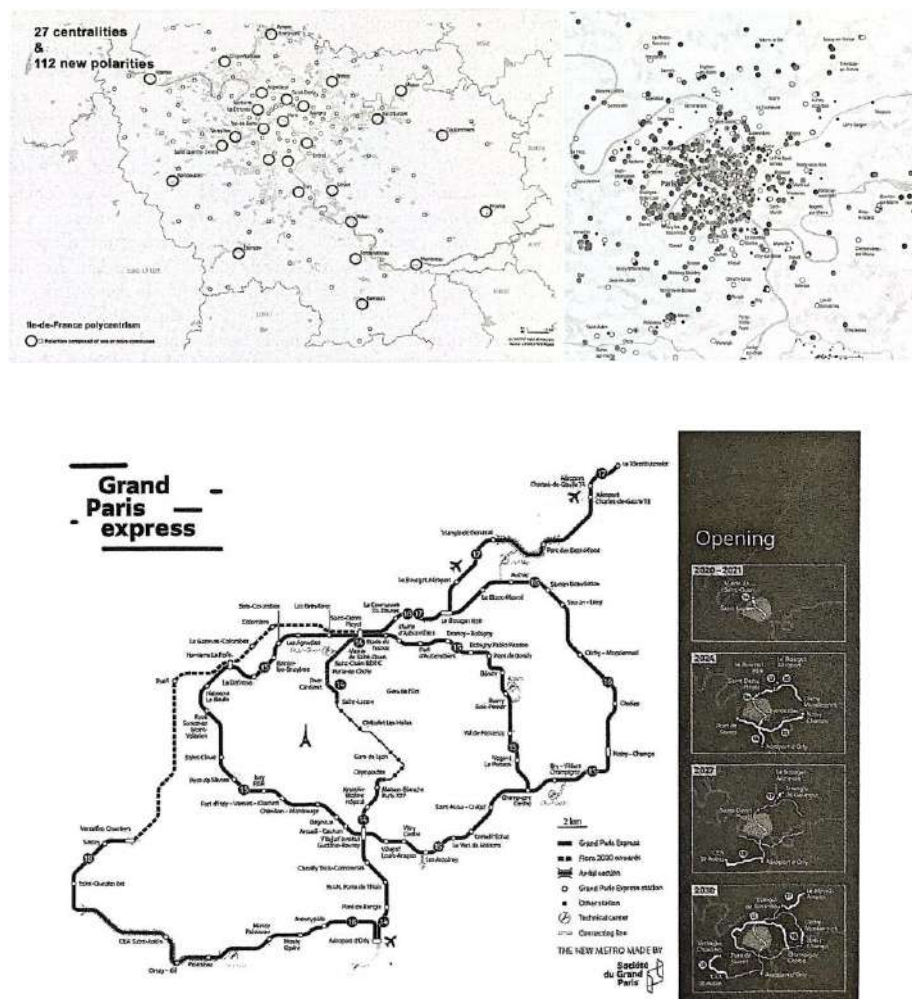


Figure 7.3 Île-de-France City Center and Sub-Center Plan (left-on); Île-de-France Third Space Plan (right-on); Grand Paris Express Plan (below) ^[34]

7.2.3 Density or accessibility: layout optimization upon driving and spatial differentiation

Under the guidance of green travel, different types of facilities within the living circle have significant differences in how they influence travel behavior. These should be categorized and combined based on their driving mechanisms (density-based, accessibility-based, or dual-driving) and the current spatial layout characteristics (along streets or not), and differentiated optimization paths should be proposed, such as “new location selection—renovation and enhancement—composite nesting” (Figure 7.4).

Learning Facilities (e.g., Primary Schools, Kindergartens)

Educational facilities have a strong accessibility-driven effect on green travel, especially as their main service targets are children, for whom alternatives to travel are limited, and safety requirements for commuting to school are high. Therefore, emphasis should be placed on "neighborhood layout" and "point-based configuration." Currently, such facilities are mostly located within residential quarters on non-street land. Strategies should prioritize building new facilities at the heart of residential quarters, ensuring that school commutes remain within a reasonable radius. Additionally, street renewal and school gate design should focus on improving pedestrian safety and green environments, and schools should be encouraged to offer flexible opening times for their sports and cultural spaces, promoting integration and shared use of school facilities with neighborhood functions (Table 7.3).

Shopping Facilities (e.g., Community Commerce, Delivery Stations)

Shopping facilities are a typical dual-driving type, influenced both by density and accessibility, due to their high frequency of use and flexibility. These facilities should focus on improving both density and accessibility. They are often located along streets and embedded in ground-floor spaces. New establishments should be sited along major streets and at road junctions with high accessibility. Renovation should focus on activating ground-floor spaces and updating street segments to enhance interface continuity. The composite path should encourage the development of mixed-use street layers to create service-oriented lifestyles, promoting “street-as-service” connectivity.

Caring Facilities (e.g., Pharmacies, Clinics, Gyms)

Caring facilities are primarily driven by accessibility, though they also exhibit some sensitivity to density. Their target audience is diverse, and their selection is more flexible. Thus, their renewal should focus on both proximity and density, enhancing ease of use.

The current layout often combines both street-facing and independent sites. New locations should be built in areas with high population density and service gaps, aiming to improve regional equity. For renovations, underused medical facilities should be revitalized and repurposed for additional functions, such as rehabilitation or psychological counseling. Composite paths can introduce mobile clinics and home care points, exploring the mixed-use potential of health services at street corner nodes or elevated spaces.

Enjoying Facilities (e.g., Cultural Activity Centers, Parks)

Enjoying facilities are primarily density-driven, but are not essential, with low travel frequency and green travel impact. Updates should focus on adaptability and flexibility based on location. Currently, these facilities are mostly distributed as point-based, non-street facilities, constrained by spatial resources and investment scales. New strategies should focus on embedding small-scale facilities at street corner nodes or small plots, enhancing daily accessibility and spatial distribution balance. Renovations should focus on micro-space activation, such as optimizing the boundary environment of small parks or platforms. Composite strategies should leverage standing spaces for green roof extensions, leisure spaces under bridges, and cultural corners.

Renovation Methods Summary

Renovation and new construction strategies can be summarized as follows^[181]:

- **New construction paths** should focus on filling gaps and optimizing structures, including:
 - 1 Embedding facility nodes in core plots, prioritizing educational and healthcare facilities in the heart of residential quarters.
 - 2 Adding continuous service nodes along streets, with high-frequency commercial facilities forming high-density service corridors.
 - 3 Precisely adding facilities in service gaps, particularly in low-accessibility areas.
 - 4 Integrating multifunctional units to create composite environments, such as combining education, leisure, and commerce.
- **Renovation and composite paths** should focus on activating existing spaces and enhancing service flexibility, including:
 - 1 Revitalizing idle ground-floor spaces, such as converting commercial ground floors and old factories into community facilities.
 - 2 Promoting time-sharing of cultural and sports facilities to improve space

utilization efficiency.

- 3 Expanding vertical composite spaces, utilizing rooftops, under-bridge areas, and other unused spaces for multifunctional uses.
- 4 Creating mobile service points such as mini delivery stations or roaming markets to offer flexible service options.

Conclusion

The optimization of facilities for green travel should start from the functional type of facilities, considering the current spatial layout and differences in behavior mechanisms. By precisely matching and flexibly responding within the "driving mechanism—form—path" three-dimensional logic, this strategy can provide a spatialized expression tool for the “facility layout—travel response” collaborative mechanism, thus enhancing the ability of the living circle's spatial structure to support green travel. This strategy should be incorporated into urban detailed planning and specialized facility planning systems.

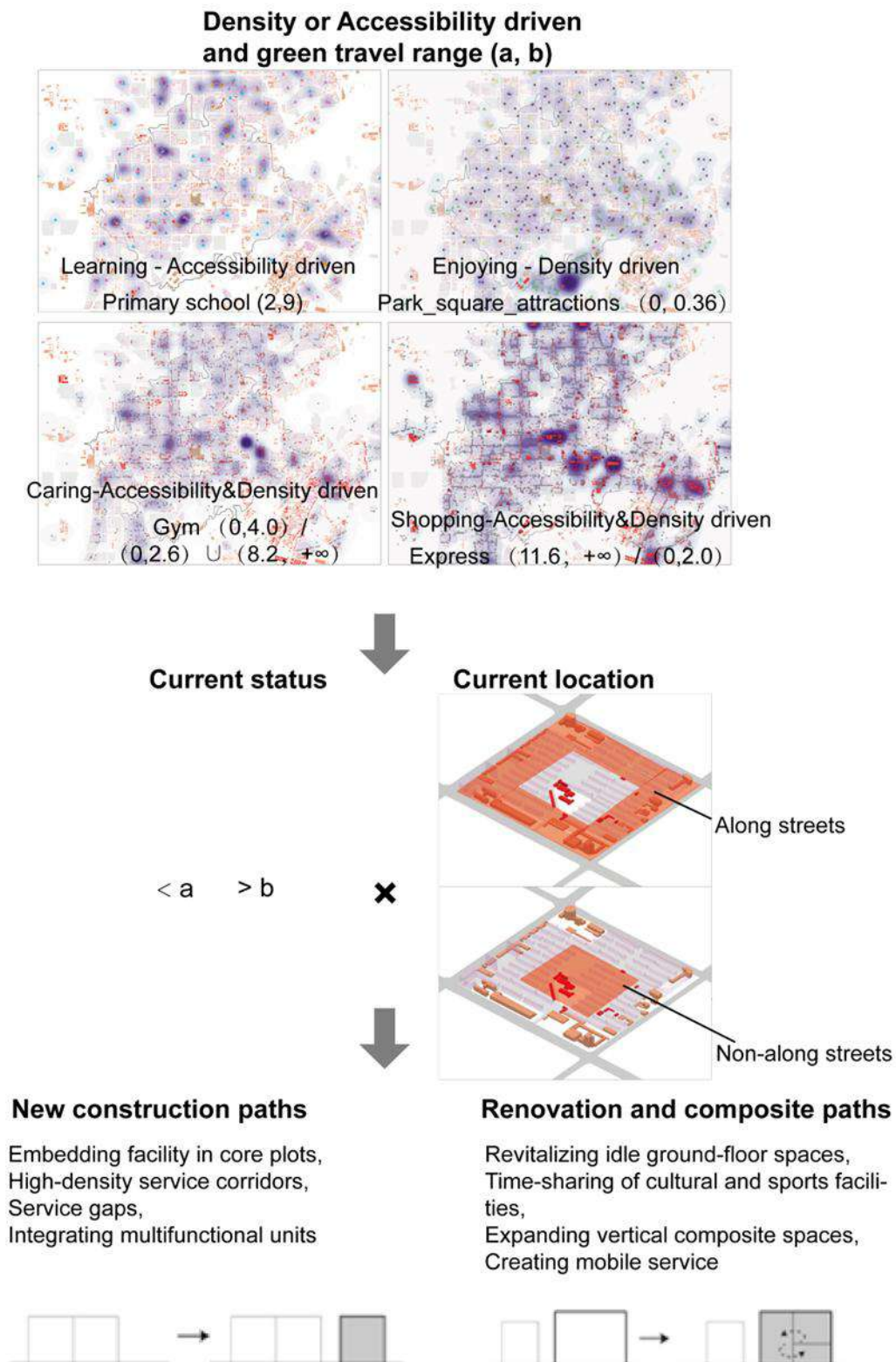


Figure 7.4 Facility density and accessibility optimization suggestions

Table 7.3 Facility density and accessibility optimization strategies based on green travel driving mechanisms and spatial differentiation

Facility Type	Green Travel Driving Mechanism	Subcategory Type	Range (_ min unit: minutes walkable; denw unit: units/km ²)	Current Spatial Layout	New Construction Path	Retrofit and Composite Path
Education Category	Accessibility-driven	Junior High mid_min	(8, 16.3)	Non-street-facing, independent deployment	Control service radius, new construction in residential core areas	Optimize school commute environments, promote "time-shared sharing" of school sports facilities
		Primary School prima_min	(2.1, 8.6)			
		Kindergarten kinder_min	(0, 4.3) $\cup$ (8.2, $+\infty$)			
Commercial Category	Density + Accessibility Dual-driven	Malls superdenw/super_min	(3.4, $+\infty$) / (0, 6.1)	Street-fronted, embedded retail type	Adding new nodes along streets, forming continuous high-density service belts	Activating street-level commercial interfaces, promoting "street-as-service" composite development
		Vegetable markets vegdenw/veg_min	(7.7, 14.9) / (2.1, $+\infty$)			
		Catering caterdenw/cater_min	(0, 81.0) $\cup$ (215, $+\infty$) / (1.8, $+\infty$)			
		Express delivery expredenw/expre_min	(11.2, $+\infty$) / (0, 2.0)			
		Community commercial outlets cmoldenw/cmold_min	(0, 183.8) / (0, 1.1)			

Table 7.3 Facility density and accessibility optimization strategies based on green travel driving mechanisms and spatial differentiation (Continued)

Facility type	Green travel driving mechanism	Subcategory type	Range (_ min unit: minutes walkable; denw unit: units/km ²)	Current spatial layout	New construction path	Retrofit and composite path
Health category	Density + accessibility dual-driven	Gyms gymdenw/gym_min	(0,4.0) / (0,2.6) $\cup$ (8.2, $+\infty$)	Mixed (partially street-fronted/partially independent)	Balanced supplementary construction across districts, considering population density and service gaps	Converting idle spaces into health service stations, embedding shared facilities
		Pharmacies phardenw/phar_min	(14.2,35.4) / (0.2,2)			
		Hospitals and clinics healthdenw/health_min	(0,14.4) / (0, 1.9)			
Leisure category	Density-driven	Parks, squares, and attractions parkdenw	(0, 0.4)	Non-street-fronted, scattered distribution	Embedded new construction in street corners and marginal spaces	Multifunctional composite use of rooftop green spaces, under-bridge areas, etc.
		Cultural activity centers cultudenw	(0,1.0) $\cup$ (3.2, $+\infty$)			
		Community service centers cmsvdenw	(6.4, $+\infty$)			

The 15-minute city plan in Paris focuses on enhancing accessibility to improve residents' convenience. The Paris City Planning Agency (APUR), a non-profit organization affiliated with the Paris municipal government, has launched an online column featuring accessibility maps for X-minute reachable areas^[183]. These maps provide real-time information on the accessibility and convenience of various facilities in Paris, offering solid and reliable evidence for the city government to identify facility gaps, enhance accessibility, and develop related urban planning strategies (Figure 7.5).

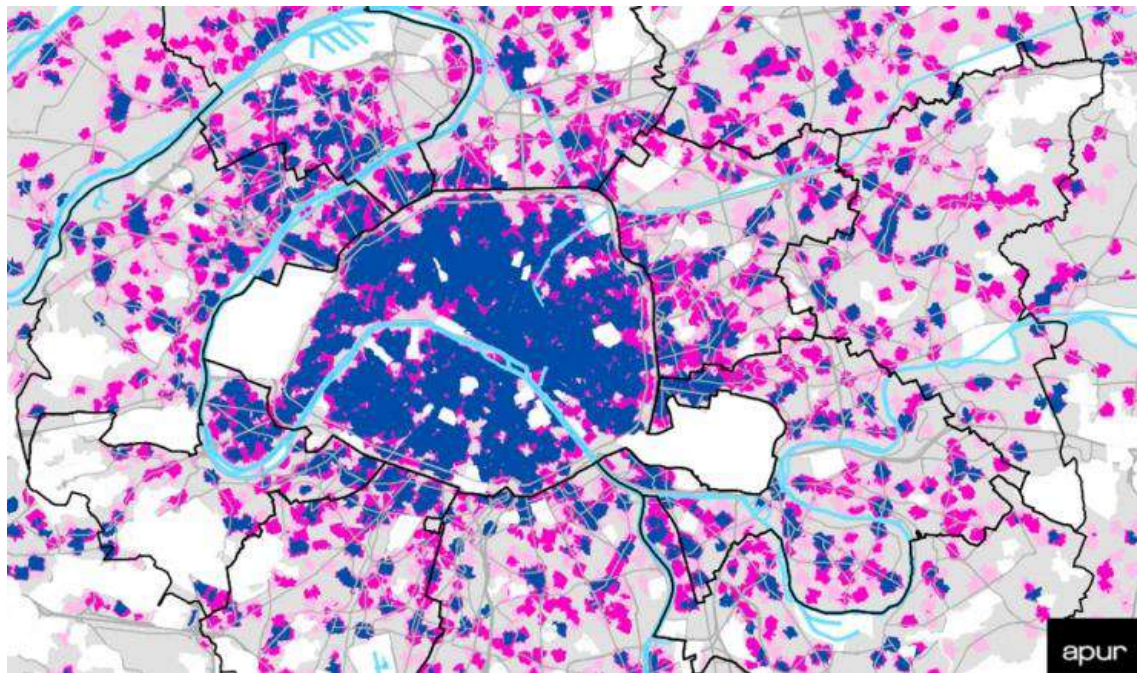


Figure 7.5 Conduct accessibility analysis of three types of facilities, namely bakeries, pharmacies, and newsstands, in the urban and suburban areas to identify depressions and update facilities^[183]

(Note: Blue represents residents who can visit all three facilities within 5 minutes; dark pink represents residents who can visit two of them within 5 minutes; light pink represents residents who can visit one of them within 5 minutes; gray represents residents who need more than 5 minutes to reach any of the facilities.)

7.2.4 Road condition: street design and density improvement upon mechanism and spatial differentiation

In the context of green travel, the structure and function of street spaces should be updated differently according to facility types. This study proposes a unified street update framework based on the green travel impact mechanisms, integrating A/B/C mechanism

variables. The framework includes a "zoning–classification–three techniques" strategy. The "zoning" refers to whether the street meets the green travel threshold, "classification" refers to differences between wall and non-wall interfaces, and "techniques" include three spatial intervention methods: morphological transformation, plant supplementation, and street furniture implantation. Streets should be updated with targeted enhancements for poorer features (Figure 7.6).

For **Class A** common variables (such as main road length, integration, street continuity, etc.), the updating area is recommended to be divided into "low threshold zones" and "high zones," with differential treatment based on street interface type. For example, main road length should be controlled at 250–360 meters; shorter streets should be connected through corner construction and slow-movement corridors, which are part of "morphological transformations." For longer streets, turn paths and corner nodes can be set to break the scale pressure. Street continuity should be maintained between 0.5–0.6 for better walkability to commercial facilities. In cases of insufficient continuity, wall-side streets should be reconstructed with facades, while non-wall-side streets can incorporate street green spaces and window nodes, enhancing accessibility through "morphology + plants + furniture" reconstruction. Variables like width-to-height ratio and building height can be optimized by integrating facades and street perception safety without major demolition (Table 7.4).

For **Class B** variables, such as greening coverage (NDVI) and non-residential floor area ratio, which reflect the differences in facility mechanisms, street updates can also follow the "zoning-classification" logic. For example, cultural facilities should match street sections with medium green coverage between 0.16 and 0.22, while vegetable markets prefer streets with an open green interface, ranging between 0.19 and 0.22. Streets with insufficient greenery in the update areas can enhance continuity through hedges or vertical greening on the wall side, while non-wall sides should clear passageways to avoid excessive greenery that could reduce vitality. Regarding non-residential floor area ratio, middle schools and vegetable markets are better suited to residential-dominated streets ($D\_no\_re\_bd < 0.6$), while cultural facilities are more compatible with mixed-function streets ($D\_no\_re\_bd > 0.6$), requiring a guiding approach to integrate commercial functions or adjust the density to organize street functional sequences, creating green travel-friendly spaces (Table 7.5).

For **Class C** mechanism variables, medical, educational, and cultural facilities

exhibit unique street adaptation mechanisms, which require targeted optimization based on sensitive variables. For example, the green travel improvement for hospitals relies on a combination of street function mix (0.9–1.5) and task support (0.4–0.6). Updates should embed convenient facilities and enrich street complexity. Cultural activity centers should be placed in streets with enjoying facility densities between 9.4–20 per km² and optimize street openness and node recognizability. Middle schools should be located in streets with higher integration densities, enhancing node density, street continuity, and walkability to build a sustainable green commuting network. For streets with values significantly higher than the threshold upper limit, updates should avoid function overlaps, instead focusing on primary function guidance, function reduction integration, facade relaxation, and spatial retreat to optimize interface recognizability and path continuity, avoiding overcomplicated functionality that hinders the green travel experience (Table 7.6).

In summary, although the mechanisms of **Class A, B, and C** variables are significantly different, they can all be integrated into a three-phase update framework: "design–density as the main axis, based on threshold intervals, combined with wall classification." The three techniques for intervention are: ① **Morphological transformation** — such as corner construction, turning nodes, and path integration; ② **Plant supplementation** — such as street trees, boundary hedges, and transparent green interfaces; ③ **Street furniture and facility placement** — such as window displays, arcades, and street nodes. These three methods can be flexibly combined to achieve layered updates based on facility types and street interface features.

Furthermore, during the process of new facility construction or relocation, priority should be given to matching street sections with green travel compatibility. For example, educational facilities like primary and middle schools should be placed in streets with moderate integration, good enclosure, and reasonable residential density. Hospitals and cultural facilities should be located in streets with high functional complexity, dense nodes, and open green spaces to ensure the feasibility and willingness of residents to engage in green travel from the outset.

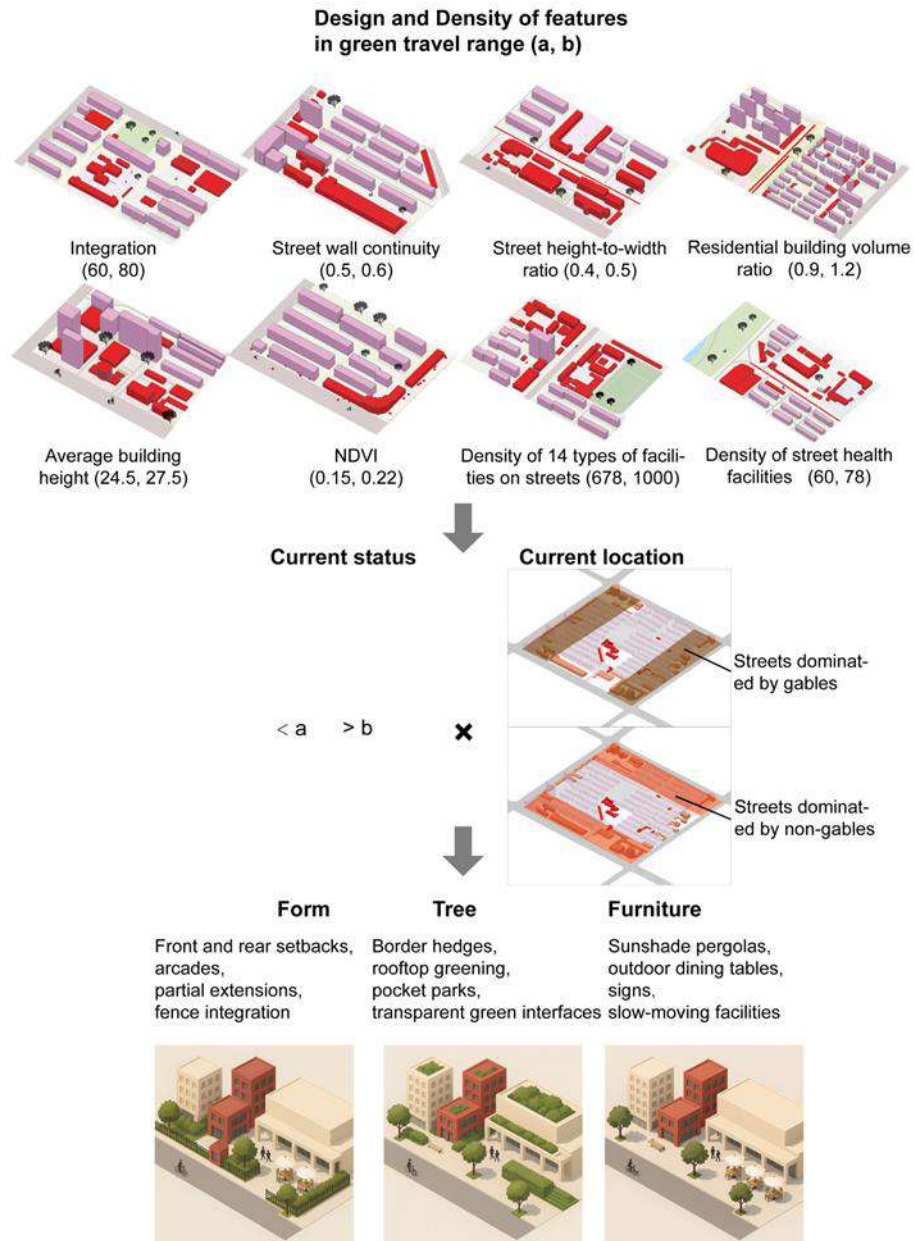


Figure 7.6 Street Design and Density Optimization Recommendations.

Table 7.4 Type A factors renewal guidance

Variable_road	Intersection (a, b)	Destination facilities	Dominant type	Renewal area below threshold a	Renewal area above threshold b	Approach
length	(250,360)	Supermarkets, cultural activity centers	Non-gable side	Enhancing cross-street connectivity, completing path networks, forming superblocks, converting existing roads into public spaces	Staggered layout, alleyway penetration, folded ground-level interface design, creating corner plazas, adding visual openings and temporary activity nodes as spatial interruptions	Gable and non-gable sides
continuity	(0.5,0.6)	Community commercial, supermarkets	Non-gable side	Adding corner plazas, interface greening or transparent street nodes	Introducing high-transparency interfaces, mixed-use functions or perforated facades	Gable side
				Street interface integration, small facility supplementation and street furniture arrangement	Street-side pocket green spaces, semi-open arcades or display window installation	Non-gable side
height	(0.4,0.5)	Hospitals, primary schools	None	Guiding corner node establishment or embedding small-scale ground-level facilities	Street setbacks, partially open interfaces or pocket spaces	Gable side
				Street furniture, green belt compensation, facade integration, fencing interfaces	Elevated ground floors, front landscaping or recessed entrances	Non-gable side

Table 7.4 Type A factors renewal guidance (continued)

Variable_road	Intersection (a, b)	Destination facilities	Dominant type	Renewal area below threshold a	Renewal area above threshold b	Approach
D_re_bd	(0.9,1.2)	Supermarket s, hospitals, primary schools	None	Guiding medium-density development supplementation or enhancing slow-traffic connectivity	Focusing on the synergistic optimization of traffic organization and pedestrian comfort	Gable and non-gable sides
INT	(60.0,80.2)	Supermarket s, park attractions squares, primary schools, community commercial facilities	None	Connecting discontinuities, enhancing path continuity, and improving local intersection design	Avoiding direct placement of educational and leisure facilities thereon, employing traffic calming measures, interface tightening, and other means	Gable and non-gable sides
heimea	(24.5,27.5)	Junior high schools, park attractions squares, vegetable markets	None	Facade remediation, interface renovation, and localized additions	Adjusting street cross-sections or implementing front/rear setbacks	Gable and non-gable sides

Table 7.5 Type B factors renewal guidance

Variable_road	Intersection	Union	Destination facilities	Renewal area below threshold a	Renewal area above threshold b
ndvi_mean	——	(0.15, 0.22)	Junior high schools, cultural activity centers, vegetable markets, community commercial facilities	Reducing hardened streets or wall isolation, introducing street trees, implementing vertical greening and boundary hedges	Clearing visual corridors, optimizing interface transparency, creating green-transparent interfaces
D_no_re_bd	——	(0.3, 1.2)	Supermarkets, junior high schools, cultural facilities, primary schools, vegetable markets	Guiding the injection of composite functions such as street-side shops and community supporting facilities	Guiding reduction-oriented renovation or functional reorganization, relieving overcrowded functional nodes, introducing transitional spaces to modulate user experience

Table 7.6 Type C factors renewal guidance

Variable_road	Intersection	Destination facilities	Dominant type	Renewal area below threshold a	Renewal area above threshold b	Approach
Func_mix_4	(0.4,0.6)	Hospitals	Non-gable side	Supplementing neighborhood-oriented functions	Emphasizing primary function guidance, avoiding spatial interference and cognitive load	Gable and non-gable sides
Func_mix	(0.9,1.5)	Hospitals	Non-gable side	Same as above	Same as above	Gable and non-gable sides
D_ALL14	(677.9,1000.0)	Junior high schools	Non-gable side	Guiding the implantation of small-scale educational, sports, and convenience nodes around schools for time-shared usage	Optimizing layout order and passage coherence, streamlining functional hierarchy, relocating non-essential facility nodes, implementing setback treatments and facade enhancements	Gable and non-gable sides
D_LEISURE	(9.4,20.0)	Cultural activity centers	None	Deploying composite leisure nodes including park attractions squares and cultural activity centers	Enhancing interface quality, creating culturally themed blocks	Gable and non-gable sides
D_HEALTH	(60.0,78.0)	Park attractions squares	Non-gable side	Integrating health nodes along park access routes to form "vitality corridors"	Functional integration and facade harmonization, strengthening facility order and recognizability	Gable and non-gable sides

Parisian neighborhoods in French are promoting green travel through street renovations, including remodeling intersections, reducing space for vehicles and returning it to pedestrians (Figure 7.7). Furthermore, increasing green cover through vertical planting provides shade and rest areas for pedestrians. Furthermore, the sense of enclosure and height-to-width ratio of streets have been improved, providing a valuable reference for future green street renovations^[183].

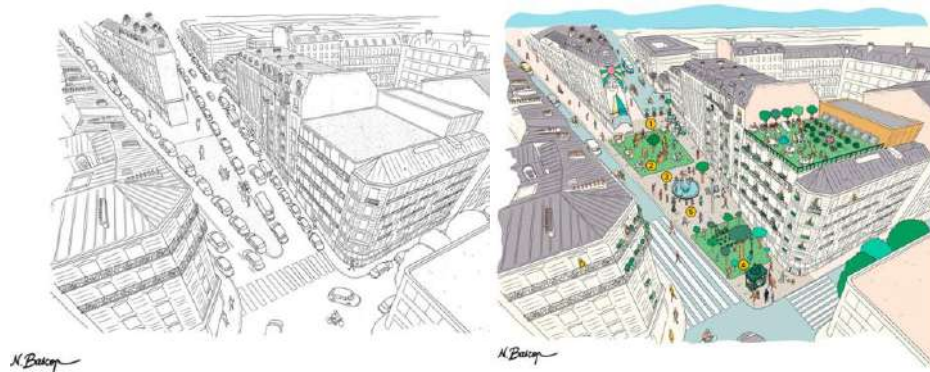


Figure 7.7 Comparison of design drawings before and after renovation of a certain block in Paris^[183]

7.2.5 Accessibility: primary school-centered organization

Primary schools occupy a central role in both the green travel mechanism and spatial organization of neighborhoods. Not only are they the natural anchor points of neighborhood structure, but they are also a key element of the neighborhood unit theory. Regression analysis shows that primary schools are the most important accessibility-related variable for green travel, with walking accessibility times ideally controlled within 2.1 to 8.6 minutes. In situations where resources are limited, priority should be given to the balanced layout of primary schools, followed by markets, and complemented by cultural activity centers to ensure that residents' daily activities are completed within a short radius. From a spatial morphology perspective, primary schools are often located in the central areas of non-street-facing residential blocks, making them suitable as multi-functional hubs in the neighborhood.

In Paris' "15-minute city" practice, primary schools are considered the core of the neighborhood unit. As the Mayor of Paris stated, "the school, capital of my neighborhood," the city not only guarantees educational services but also opens classrooms, playgrounds, and other spaces to the public, while transforming the

surrounding streets into green, walkable areas^[34]. An example of this is the "Streets for Children" project, where roads are temporarily closed during the spring and autumn, transforming them into spaces for play and social interaction (Figure 7.8). Currently, 42 primary schools and 28 kindergartens are open to the public, comprising about 1/20 of the total, creating a community core that integrates both time and functionality. This experience demonstrates that primary schools can serve as the spatial center of a neighborhood, while also incorporating cultural, sports, and social functions to build a community core that is accessible daily, open, shared, and green-friendly.



Figure 7.8 Primary school-centered urban renewal project in Paris

7.2.6 Density and accessibility: optimization of low green travel living circles

Among the six major mechanism dimensions, density and accessibility are the direct drivers of green travel. Their enhancement not only significantly improves service levels of facilities but also indirectly influences diversity, road conditions, and community collaboration, thus creating a closed loop that transitions from physical space optimization to behavioral changes. This section proposes differentiated improvement strategies for three typical low green travel living circles—"Near-Rural Porous Type," "Hollow-core Type," and "Fan-Shaped Radiation Type"—with a focus on density and accessibility.

(1) Near-rural Porous Type: density optimization to fill gaps

These living circles are often located at the urban-rural fringe, characterized by "dense inside, sparse outside" and gap distribution patterns. The facility density is low and unevenly distributed. The strategy should prioritize filling the gaps of high-frequency facilities, such as vegetable markets, fresh food supermarkets, and courier stations, within

the 15-minute walking circle. The density targets are 7.8–14.9, 2.2, and 12 facilities per square kilometer, forming a balanced coverage for daily service networks. At the same time, the density of low-frequency facilities such as gyms should be controlled to prevent the waste of spatial resources.

Regarding accessibility, walking time to high-frequency facilities like pharmacies, health services, and community commerce should be compressed to around 2 minutes, and the walking time to primary schools should be controlled within 8.6 minutes. Additionally, breakpoints in the walking network should be eliminated to ensure continuous paths between residences and facilities (Figure 7.9).

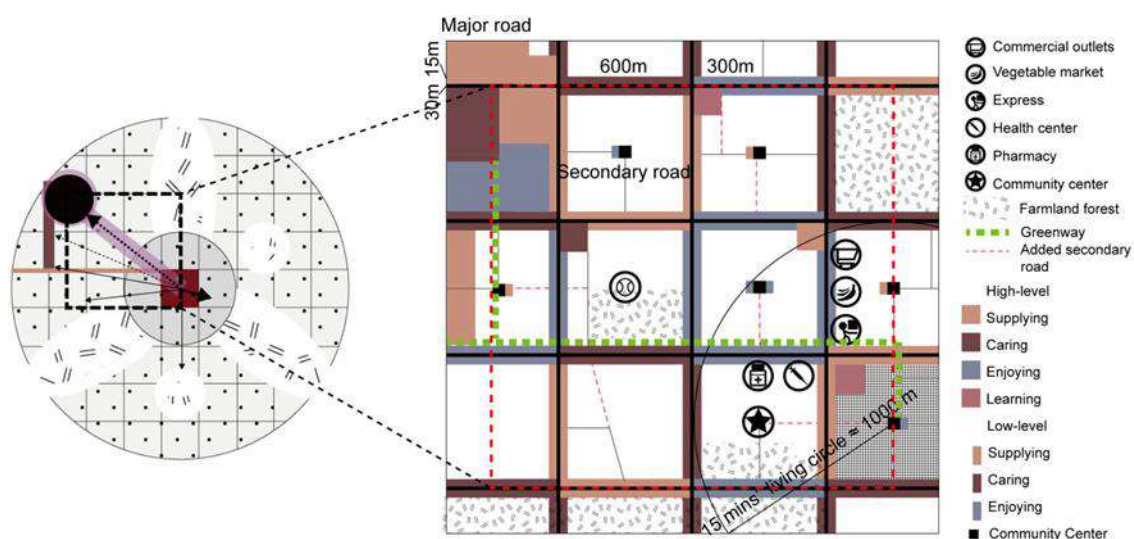


Figure 7.9 Schematic diagram of the renewal of the Near-Rural Porous Living Circle

(2) Hollow-core Type: filling the core

This type is common in new development zones or areas undergoing redevelopment, where there are very few service facilities within the walking circle, and residents rely on cycling or long-distance travel. The density improvement should focus on commercial and community services within the walking circle. Priority should be given to using street-level commercial spaces and setback areas to add supermarkets (≥ 3.4 per km^2), courier points (≥ 11.6 per km^2), and community service stations (≥ 6.4 per km^2). Some concentrated green spaces should be transformed into pocket parks or community greenways to improve green space utilization.

The accessibility strategy should aim to shorten the travel chain to core facilities. The goal is to reduce the average accessibility time for 14 types of facilities from the current 10.9 minutes to 5.4 minutes. Core nodes like primary schools and community

commerce should be added to avoid long-distance travel for daily activities (Figure 7.9).

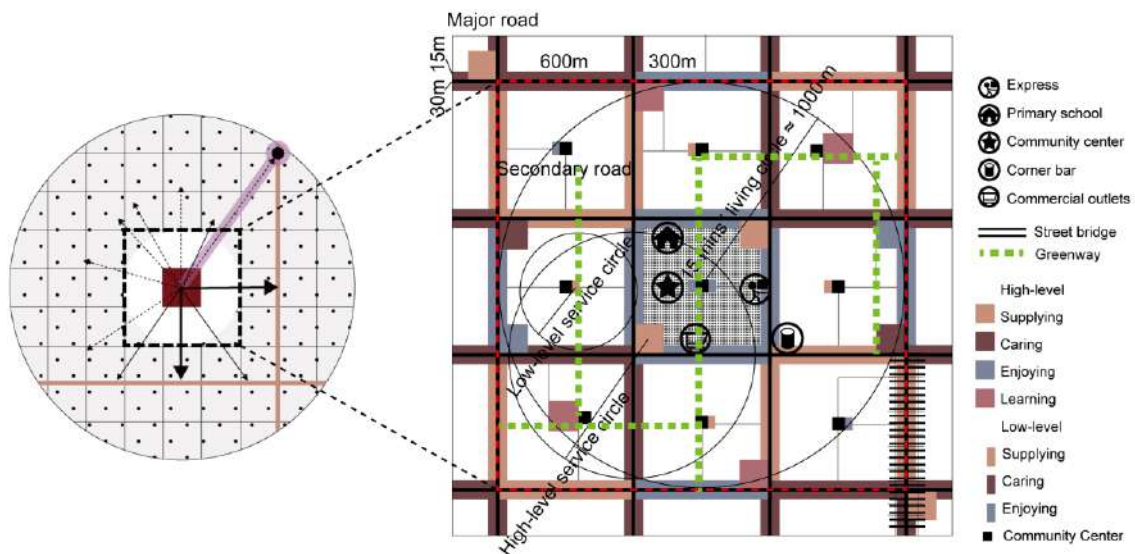


Figure 7.10 Schematic diagram of the renewal of the Hollow-core Living Circle

(3) Fan-Shaped Radiation Type: balance and network optimization

This type of living circle is often located next to industrial, office, or large park areas, with an imbalanced functional structure and facilities distributed in a fan shape with poor accessibility. The density strategy should focus on filling gaps in courier services (≥ 11.6 per km^2) and community service stations (≥ 6.4 per km^2), while controlling the excessive density of parks and vegetable markets. Land efficiency should be released through tiered utilization and dispersed facility placement.

The accessibility strategy focuses on reducing the radius of core facilities. Walking access to community commerce should be reduced to 1.1 minutes, health facilities to 1.9 minutes, and primary schools to under 8.6 minutes. Pocket parks should be built using vacant and corner plots, and the slow-moving path and public transportation/bike station network should be enhanced to ensure efficient connections between residential quarters and external large facilities (Figure 7.11).

(4) Synthesis and integration

Regardless of the type, density and accessibility serve as the dual anchor points for optimizing green travel spaces: density improvement ensures that services are "available and of good quality," while accessibility optimization guarantees that residents can "reach services close by." The coordinated improvement of both can drive comprehensive improvements in diversity, road continuity, and community governance, creating a system path from facility supply to behavioral guidance.

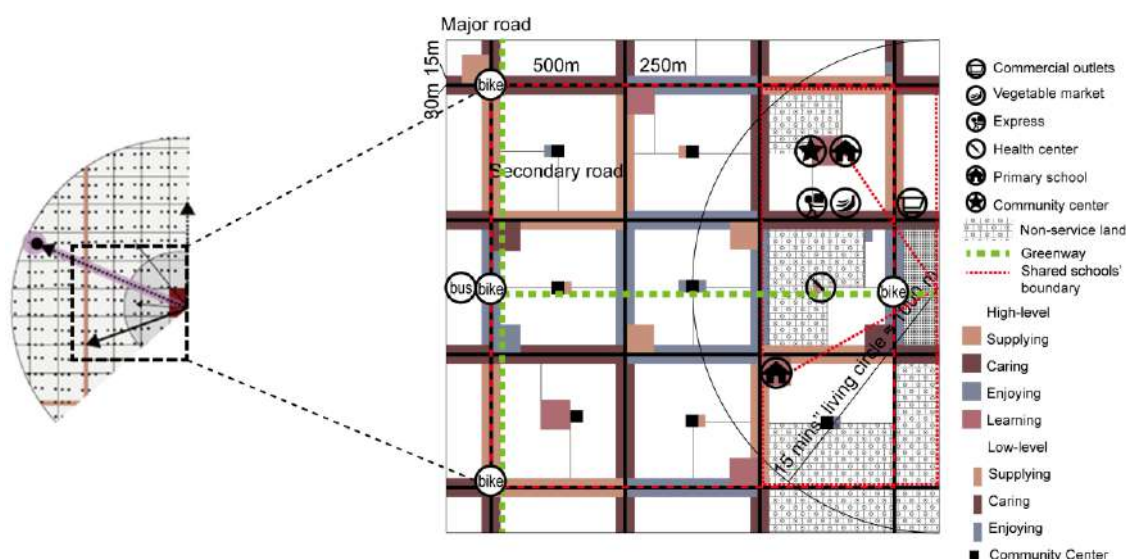


Figure 7.11 Schematic diagram of the renewal of the Fan-Shaped Radiation Living Circle

For planning implementation, the strategy should integrate with the city's central and sub-central systems and the slow-moving network. Large facilities should be placed at main roads and commercial corridor nodes, while small and medium-sized facilities should be embedded within the walkable range of community interiors^[187]. This will achieve a deep match between the urban structure and the living circle network, promoting the transformation of low green travel living circles into high-density, highly accessible, balanced, and sustainable spatial forms (Table 7.7).

Table 7.7 Suggestions for three types of living circles

Category	Current issues	Density optimization targets	Accessibility optimization targets
Peri-urban Porous Type	Dense internally, sparse externally; uneven facility distribution; numerous slow-traffic discontinuities	Vegetable markets 7.7–14.9 units/km ² , fresh supermarkets 2.2 units/km ² , express delivery 12 units/km ² ; controlling excessive gym density	Pharmacies, health services, commercial ≤2 minutes walking; primary schools ≤8.6 minutes; connecting slow-traffic networks

Hollow-core Type	Scarce walking-circle facilities, residents reliant on long-distance travel	Supermarkets ≥ 3.4 units/km ² , express delivery ≥ 11.6 units/km ² , integrated community service stations ≥ 6.4 units/km ² ; pocket parks enhancing green space accessibility	Comprehensive accessibility reduced from 10.9 to 5.4 minutes walking; primary schools ≤ 8.6 minutes; shortening travel chains
Fan-Shaped Radiation Type	Unbalanced functional structure, facilities concentrated unilaterally	Express delivery ≥ 11.6 units/km ² , integrated community service stations ≥ 6.4 units/km ² ; parks and vegetable markets distributed dispersedly	Commercial ≤ 1.1 minutes walking, health facilities ≤ 1.9 minutes, primary schools ≤ 8.6 minutes; pocket parks + slow-traffic + transit/bicycle networks

7.3 Summary

This chapter explores the key factors and optimization of green travel facility layout within a 15-minute cycling living circle. By integrating the findings of three studies, it is shown that accessibility, density, and road conditions are key drivers of green travel and the primary cause of differences in green travel behavior. Accessibility plays a dominant role in both facility destination selection and travel mode choice, with shorter distances significantly promoting green travel. This chapter also explores the varying importance of different facility types. For example, markets and primary schools have a significant impact on green travel, while health and leisure facilities are driven by both accessibility and density. Street design, including factors such as street length and integration, plays a crucial role in green travel mode choice. Furthermore, the study identifies three types of low-green travel living circles—suburban porous, hollow, and fan-shaped radial—that require targeted interventions to improve density and accessibility. Finally, based on empirical findings of correlation and drawing on international models such as France's 15-minute city, this chapter proposes a facility renewal approach centered on the dimensional optimal range. This approach considers both the spatial differentiation and spatial dimensions of facilities, emphasizes a collaborative, multidimensional planning approach, and integrates facility-centered and residential-centered strategies. This provides an actionable reference for green and sustainable mobility urban planning.

CHAPTER 8 CONCLUSIONS

8.1 Main conclusions

Against the backdrop of global warming and carbon reduction targets, the high proportion of motorized short-distance travel in communities and persistently high carbon emissions have become pressing challenges. The systematic development of 15-minute living circles currently offers an opportunity to address this issue. As the primary space for residents' daily activities and a key venue for the transition from green to motorized travel, living circles have the potential to become a key target for carbon reduction planning. Therefore, focusing on the layout of living circle facilities and exploring its correlation to green travel has significant research value and practical significance.

Against this backdrop, this paper, starting from the perspectives of "all-category travel versus single-category travel" and the two stages of "destination choice versus green travel mode selection," decomposes the goal of a high-level "green travel living circle" into three sub-goals: (1) encouraging green travel for all-type facilities travel; (2) avoiding long-distance travel for single-type facilities; and (3) promoting the choice of green travel modes for single-type facilities. Using six dimensions—attitude, density, scale, diversity, accessibility, and road condition—as explanatory variables, a framework for the correlation between living circle facility layout and green travel was constructed, then empirical studies were conducted based on a sample of 860 15-minute cycling living circles in Tangshan. Unlike previous studies conducted at the temporal or spatial level, this study takes the residents' travel behavior chain as the main line and uses multi-level travel space as the research carrier to reveal the overall all-type pattern, single-category differences, and key mechanisms. It was found that the realization of green travel goals requires going beyond the single dimension of accessibility, and facility optimization design strategies based on multi-dimensional thresholds were proposed. Through this logical chain of "Goal-Mechanism-Strategy", the study not only constructed a cross-level, multi-objective analytical framework, but also achieved a complete closed loop from numerical mechanism to spatial strategy, providing systematic support for revealing the inherent mechanisms and practical paths of facility layout and green travel.

Although this study uses Tangshan as a case study, the analytical framework and

threshold system it constructs have strong cross-city applicability and can be contextualized according to city characteristics. Overall, the method of this study is particularly applicable to three types of cities: (1) medium-sized industrial transformation cities, where cycling and walking are important modes of commuting and daily travel, and the spatial structure of the living circle is similar to that of Tangshan, making it the most applicable; (2) suburbs and new towns of large cities, where spatial density is relatively moderate and the facility hierarchy system is being improved, and the threshold system of this study can be used to identify shortcomings and optimize facility layout; (3) small cities and county towns, where residents have a shorter daily life radius and a higher proportion of cycling, and the "facility layout-travel response" mechanism of this study can be directly used to identify problems in the living circle structure and propose optimization suggestions. Overall, this framework has good transferability and can be adapted according to city size, density and traffic structure, providing a reference path for different types of cities to promote living circle planning.

The main conclusions of this paper are as follows:

8.1.1 Importance, driving dimensions, and optimal ranges of different facilities in all-type green travel

Regarding all-type facilities green travel in the living area, the importance of different facility types varies. Among sub-type facilities, vegetable markets and primary schools contribute the most, while among the broader facility types, shopping and learning facilities contribute the most. The greater the contribution of a facility category, the higher its density is in the current distribution pattern, and it is distributed linearly along the street or in patches or surfaces. In terms of demand, even if the current number of high-contribution facilities is high, residents still frequently mention and suggest supplementing them. Therefore, planners should optimize living circle facilities based on the level of contribution.

Significant differences also exist in all-type green travel driving dimensions across different facility types. Learning facilities are primarily driven by accessibility, but enjoying facilities by density, while shopping and caring facilities by both accessibility and density. This difference is related to travel choices. Residents only need one primary school, thereby increasing the density of primary schools does not significantly change their travel choices. However, residents demand a large number of leisure facilities, so

the high-density layout and increased diversity of cultural activity centers influence travel choices and thus increase the likelihood of green travel.

Different facility types also have different optimal ranges for all-type green travel. Most facilities accessibility indicators exhibit a monotonically decreasing correlation, such as supermarkets, community businesses, express delivery services, health services, pharmacies, and parks. Most facilities density indicators exhibit a threshold effect, with each of facility density and all-type green travel exhibiting an inverted V-shaped trend, initially increasing and then decreasing. A few types, including supermarkets, express delivery services, community service centers, and primary schools, are able to break the 'fatigue effect', with the relationship between the two showing a consistently increasing trend. Facility optimization strategies need to be tailored to different facility types so that their layouts align with the favorable ranges that promote green travel.

Low-green travel living circles are concentrated in urban suburbs, new areas or single-functional areas, and are generally characterized by low density, low accessibility and insufficient scale. The lack of key infrastructure has caused residents to choose distant places instead of nearby ones or be forced to travel long distances. In addition, the weak street design has further led to a significantly low proportion of green travel.

8.1.2 Dominant and synergistic mechanisms of accessibility, scale and road condition in single-type facility destination choice and green travel mode choice

Accessibility affects entire travel towards facility and is a rare dimension that plays a dominant role in both stages. Planning must prioritize this point.

Accessibility and facility scale play a synergistic role in destination selection for single-type facilities. Floor area is significantly correlated with most service attributes (such as comprehensive offerings, environment, and expanded functionality), making it a proxy for facility scale. The larger the facility and the closer it is to the destination, the more attractive it is and the greater its likelihood of being chosen by residents. Distance to the nearest facility and distance to the largest facility jointly influence the average trip distance within the living circle. Distance to the nearest facility has a greater impact on trips to vegetable markets than to supermarkets, emphasizing a "close, convenient, and numerous" layout. When the distance to the nearest vegetable market exceeds 2,000 meters, trip distance increases significantly, especially when the largest vegetable market

is also far away. When the distance to a vegetable market is less than 1,000 meters but the satisfaction of walking to cycling circle score is below 0.3, long-distance trips are still possible. Supermarkets are more significantly influenced by distance to the largest facility, with residents traveling outside their living circle for large, well-serviced supermarkets, especially when the largest supermarket is over 60,000 square meters and more than 2,000 meters away. Among the four types of living circle travel structures, the "flat structure, balanced distance" and "lack of neighborhood, remote dependence" living circles are located in the suburbs, with long average travel distances, long distances between the nearest and largest facilities, and imbalanced levels, and are the focus of planning.

Accessibility and road conditions play a synergistic role in the selection of green travel modes for a single facility type. Trips shorter than a certain distance and appropriate street design and density encourage walking and cycling. The dominant role of accessibility is reflected in the fact that for any single facility type, the outer diameter (OD) distance from the residential quarter to the facility has the highest weight. The proportion of green travel in an OD flow cluster exhibits a monotonic decaying relationship with distance. Within 1.2–2.3 kilometers, residents shift from green to non-green travel preferences. The walking and cycling distance thresholds for health and leisure facilities are higher than for other types of facilities; the walking and cycling distance thresholds for shopping centers are higher than for community commercial outlets. The effects of street design and density exhibit a more complex, non-monotonic relationship. Main road length, residential building volume ratio, integration, street wall continuity, and street height-to-width ratio all contribute to green travel in roughly the same range for each type of facility, making them key indicators for urban planning^[188]. Of the four types of streets, those with "inadequate support" type are located in suburban areas and feature poor street design, low density of street facilities, loose structures, and insufficient functionality, urgently requiring intervention.

8.1.3 A green travel-oriented design framework based on 'spatial hierarchy-dimensional threshold-typology'

Based on the correlation research findings, this study proposes a multi-level green travel-oriented design framework with "spatial hierarchy-dimensional threshold-typology design" as the core, aiming to build a connection path from mechanism quantification to spatial implementation, and realize the method transformation from "model cognition" to

"design operation". This framework reveals the scale-progressive relationship between facility layout and travel behavior, and constructs a multi-level design logic mediated by threshold.

(1) Spatial hierarchy: multi-level progression of city level-living circle level-street level.

Although the samples of three empirical studies are irregular travel behavior scopes, including all-type living circle, single-type living circle or OD rectangular, the space for planning strategies involved are transformed to three levels of planning space: city level-living circle level-street level. The green travel-oriented design should form a coordinated optimization mechanism in the multi-layer space: at the city level, the focus is on establishing a multi-center facility hierarchy system, with scale and accessibility as the main dimensions, and optimizing the spatial distribution of large, medium and small facilities; at the living circle level, the facility density and accessibility dimensions should be coordinated to ensure the integrity of activities and balanced services within a 15-minute range for residents; at the street level, with the road condition dimension as the core, by improving micro-space indicators such as street height-width ratio and interface continuity, it directly affects walking and cycling behaviors. The three together constitute a top-down spatial progressive logic: the city provides macro-structure, the living circle carries meso-functions, and the street reflects micro-behavior, which is the key carrier for the realization of green travel.

(2) Dimension threshold: using quantitative indicators as design anchors.

This study shows that the dimension optimal range is the core premise of green travel. Whether it is accessibility indicators, density indicators, or street design indicators, only when the corresponding optimal range is met will residents be more likely to choose green travel. The dominant dimensions and thresholds of the above-mentioned levels are different, and different dimensions and thresholds can be selected according to the planning level.

In terms of accessibility, 5 minutes to primary school, 14 minutes to junior high school, and 3 minutes to kindergarten are the key thresholds for green travel; in terms of density, vegetable markets ($7.73 - 14.88/\text{km}^2$), express delivery points ($\geq 11.57/\text{km}^2$), and community service centers ($\geq 6.41/\text{km}^2$) constitute the reasonable range for walking and cycling; in terms of road conditions, street height-to-width ratios of $0.4 - 0.5$ and residential building volume ratios of $0.8 - 1.18$ are key parameters for streets suitable for

walking and cycling.

These thresholds are not only model results, but also design goals, pushing urban planning from qualitative experience to quantitative guidance.

(3) Typological differentiation: using design techniques to achieve threshold transformation.

Thresholds define the goals and directions of design interventions, while typological design provides implementation paths and spatial expressions. Spatial design should adopt differentiated means according to the types of streets and facilities to achieve the spatial expression of quantitative goals.

For street facilities (such as commercial, medical, and fitness), green travel is mainly driven by density. Streets should maintain continuous interfaces and a reasonable height-to-width ratio. Gabled interfaces should utilize partial openings, setbacks, or pocket spaces to enhance permeability. Non-gabled interfaces should enhance continuity and accessibility through the addition of small nodes, greenery, and street furniture.

For non-street facilities (such as schools and community service centers), green travel is primarily driven by accessibility. Core facilities such as primary schools should be located in central areas with high residential density and strong connectivity. Parks and cultural facilities should be embedded in corners or along plot boundaries to create accessible and shareable spaces.

This typological approach achieves a transition from "numerical targets" to "morphological strategies," allowing thresholds to transcend statistical boundaries and become tangible at the design level.

8.2 Key innovations

This paper focuses on the question of "how to optimize the layout of facilities in the 15-minute cycling living circle to promote green travel", and innovates in theory, perspective and method. By accurately delineating the living circle, narrowing the statistical scope and decomposing the travel process, the paper constructs a cognitive and empirical framework for the correlation between facility layout and green travel. Among them, in the study of green travel with single-type facilities, the "OD flow cluster" perspective is proposed, which integrates the spatial characteristics and accessibility of multiple streets involved in travel, breaking through the traditional fragmented single street perspective. The empirical part develops an integrated "regression + clustering"

methodology based on big data and large samples, which is suitable for different research situations, reveals the complex mechanism of the layout's impact on behavior, and summarizes the improvable characteristics of unfavorable living circles and street samples. The paper provides a transferable analytical framework and operational methodological guidance for a wider range of space-behavior research.

8.2.1 Constructing a cognitive framework for the correlation between facility layout and travel behavior in living circles

A key innovation of this study lies in the proposal and construction of a cognitive framework for the correlation between facility layout within a 15-minute cycling living circle and green travel behavior. Unlike previous studies, which often simplify living circle boundaries, employ overly broad statistical scopes, or employ unclear process delineation, this framework develops a "precise delineation—narrowing the scope—decomposition" approach. First, using map navigation technology, a 15-minute cycling living circle is precisely mapped for each residential quarter. This breaks away from the traditional simplistic approach of relying on administrative boundaries or street divisions, achieving a scientific and fair boundary delineation and laying a solid foundation for subsequent correlation testing and living circle classification. Second, in measuring travel behavior, the scope is narrowed from the overall city scale to the 3-kilometer cycling living circle. This shifts the research perspective from a macro to a micro perspective, shifting from examining the impact of small-scale facility layout on large-scale travel to examining the impact of small-scale facilities on travel within these small-scale areas. This allows for a more direct exploration of the relationship between facility layout and residents' travel behavior within these small-scale areas. Secondly, the study decomposes residents' green travel behavior process, distinguishing between the "long-distance travel choice" and "travel mode choice" stages. Based on this, three sub-goals are proposed (all-category green travel, single-facility long-distance travel choice, and single-facility green travel choice). Hypotheses are then formulated along six analytical dimensions, forming a multi-level cognitive framework for spatial-behavioral correlations.

This framework not only systematically reveals the mechanisms and differential pathways of the impact of living circle facility layout on residents' green travel, but also provides a unified logical starting point and explanatory perspective for the three empirical correlation studies. By combining a large sample size, machine learning models,

interpreters, and clustering classification, this study provides a deep mechanistic understanding of how facility distribution patterns shape green and non-green travel, thus enriching the understanding of the multi-level influencing mechanisms in the field of spatial planning, from layout to behavior to travel patterns.

More importantly, this framework possesses strong transferability and disciplinary value. It is applicable not only to living circle research but also to other local spatial units with a complete "space-behavior" mapping, allowing it to analyze the coupling mechanisms between spatial layout and behavioral patterns. Its theoretical significance lies in transforming the previous macroscopic and general spatial-behavioral analysis into a classifiable, decomposable and verifiable analysis process, thus achieving refined theoretical construction and expanding the problem analysis ideas and research paths of the planning discipline.

8.2.2 Proposing an OD flow cluster perspective for single-type facility travel impact analysis

This study proposes an "OD flow cluster" perspective to explore the spatial-behavioral mechanisms underlying short-distance, single-facility travel. This approach transcends the limitations of traditional studies that focus on streets, emphasize the relationship between street characteristics and green travel, and analyze single-facility travel in a fragmented manner. By constructing a characteristic OD flow cluster system encompassing three dimensions and 25 indicators, this study systematically characterizes the spatial and behavioral relationships within a 15-minute cycling living circle, from residential quarters to facilities. This system not only integrates comprehensive spatial environmental characteristics from the origin, along the route, to the destination, but also incorporates non-spatial factors such as accessibility and attitude, often overlooked in traditional research. This shifts the research approach from a "fragmentary" perspective to a "complete chain." Empirical results demonstrate that accessibility and road conditions are key factors in explaining the impact of single-facility green travel. Streets can be categorized into four types with varying degrees of green travel support, effectively supplementing and revising the conclusions of existing research.

At the planning level, the significance of this study lies in its centralization of the behavioral chain, avoiding the one-sided focus of "discussing space in isolation." The OD flow cluster perspective emphasizes "taking behavior as the starting point" to re-examine

the space-behavior relationship, revealing the full-chain mechanism of the global spatial layout on travel behavior, and also provides strong support for formulating spatial transformation and facility optimization strategies that are more in line with actual travel needs.

8.2.3 Developing a regression–clustering methodology for large-scale spatial–behavioral correlation analysis

This paper proposes a travel mode identification method based on high-precision mobile phone signaling data, classifying approximately 20 million trip records as walking, cycling, public transportation, and driving. This method lays the foundation for large-sample empirical research and the application of a "regression-clustering" methodology. This method utilizes the AutoNavi Map navigation route planning API to identify travel modes using a "travel time comparison method." This method offers the advantages of automation, standardization, and batch processing, enabling large-scale data processing to be completed in a relatively short period of time. Sufficient travel data and sufficient travel data for each residential living circle are essential for the inclusion of more living circles. Furthermore, unlike existing studies that rely on "complete route data," this study utilizes only trip origin and destination information for identification, significantly reducing data size and computational burden while covering a wider sample of living circles with the same amount of travel data.

The paper further develops a "regression-clustering" analysis method, sequentially using a machine learning regression model to rank feature importance and capture nonlinear relationships. SHAP/PDP tools are then used to analyze threshold intervals for key variables, and clustering techniques are combined to achieve a categorical response to spatial heterogeneity. Unlike traditional linear regression methods, this methodology reveals the complex correlation between space and travel behavior and categorizes different behavioral spaces, helping planning experts grasp the underlying principles and essence within this diversity.

The methodology differs across three related empirical studies, demonstrating distinct advantages and adaptability to diverse research scenarios. In Chapter 4, analyzing mechanisms of all-type facilities green travel, a facility layout index system was constructed using a 15-minute cycling living area within a residential quarter as a sample. An XGBoost regression model was used to measure variable importance, and SHAP was

used to identify the optimal ranges of features. Subsequently, K-means clustering weighted by importance coefficients was used to divide the living areas into six categories, and key features requiring optimization were identified by combining the mean values of each SHAP. This method is applicable to Case ①: a large number of variables (approximately 50) warrants full retention; and the samples are relatively consistent in the direction and degree of promoting behavior. This method not only forms a multidimensional portrait of the living area but also allows for the extraction of promotion thresholds for green travel. In Chapter 5, analyzing green travel mechanisms across single-type facilities, an indicator system for facility layout was constructed using OD flow clusters as a sample, and a random forest model was used to measure variable importance. Subsequently, the PDP local dependency graph was used to extract optimal ranges, binarize key variables, and then classify streets into four categories using hierarchical clustering. This method is applicable to Case ②: a moderate number of variables (approximately 30), only important features need to be retained, the main effects exhibit a monotonic or piecewise monotonic trend, and sample differences are primarily reflected in whether key thresholds are crossed. In Chapter 6, analyzing the mechanisms of long-distance travel for single-category facilities, a single-category facility layout indicator system was constructed using the 15-minute cycling living circle of a residential quarter as a sample. An XGBoost model was used to screen and train 10 key indicators to assess their importance for long-distance travel, and eigenvalues and optimal ranges were calculated using SHAP. Hierarchical clustering was then performed based on the SHAP values, resulting in four categories of living circles. This method is applicable to Case ③: a moderate number of variables (approximately 30), only important features need to be retained, the effects exhibit nonlinearity, and samples are similar in the degree to which they promote behavior, but the characteristics may be consistent (linearly correlated with the dependent variable) or significantly different (nonlinearly correlated with the dependent variable). This methodological framework is flexible and transferable, allowing researchers to choose and adjust their analytical approach based on their research needs—whether to retain all independent variables or only the most important ones, whether to emphasize inherent data-driven models or outcome-oriented characteristics, and whether to simplify and consider segmented trends or comprehensively consider holistic mechanisms.

These techniques and methods provide new analytical and decision-making tools for

planning, helping to identify key spatial planning features and patterns for specific behavioral goals and further clarify corresponding optimization and transformation strategies. This is reflected in three aspects: First, they can identify the mechanisms by which facility layout influences specific travel behavior goals and identify the most decisive spatial elements. Second, they can reveal the characteristics of the impact of these key elements on behavioral goals and further determine whether they should be strengthened, moderately controlled, or maintained within a certain range during planning interventions, thereby providing precise numerical references and thresholds for planning and design. Third, by classifying and summarizing spatial patterns, they can delineate typical spatial forms that meet the goals and spatial characteristics that do not, providing a scientific basis for identifying "spaces that should be learned and replicated" and "spaces that require key transformation and optimization."

8.3 Limitations and future outlooks

Given the limitations in the author's cognitive capacity, research time, and scope of investigation, while this study has made breakthroughs in theoretical construction and methodological exploration, several limitations remain:

First, the travel representativeness of mobile signaling data is restricted. This study only conducts cross-sectional analysis based on a single period of data from October 2020 and does not include continuous multi-period travel sequences. Therefore, the long-term impact mechanism of facility space evolution on green travel has not been explored. Future research can introduce long-term tracking data to analyze the dynamic impact of facility layout changes on residents' travel behavior and summarize facility update paths and intervention strategies that can guide green travel.

The single-city case study limits the broad applicability of the research. Since the author participated in the planning work of the "Tangshan Convenient Quarter-Circle Life" at the initial stage of the topic, Tangshan, as one of the first pilot cities for the living circle and a pilot for urban renewal, holds significant policy foresight and practical feedback value. Therefore, this study uses Tangshan as a case for empirical analysis. However, the research background of a single city may influence the universality and generalizability of the conclusions. Future research could expand to multiple types of cities or regional samples to verify the general applicability of the green travel living circle construction mechanism, enhancing the theoretical explanatory power and policy

guidance effectiveness of the findings.

In this study, the analysis of single-facility destination selection focuses primarily on two types of shopping facilities: malls and vegetable markets, and does not cover other types of facilities such as education, healthcare, and leisure. The travel choice mechanisms for these facilities may vary significantly. For instance, the selection of educational facilities is constrained by school district affiliation, healthcare facilities depend more on wellness adaptation, and leisure facilities often rely on individual preferences. Therefore, long-distance travel behavior may not necessarily be dominated by facility scale but may be driven by institutional constraints or individual preferences. Future research could focus on systematically exploring the relationship between long-distance selection behavior and facility attributes for different functional types of facilities, further expanding the adaptive explanatory framework for green travel behavior.

This study distinguishes between facility types and focuses on the impact mechanisms of single facilities corresponding to travel behavior. For example, it identifies the positive influence of health facilities on park and square-type travel and proposes planning suggestions for combining the two types of facilities. However, the collaborative effects between facilities have not been systematically explored. In reality, the mixed layout of multiple facilities may generate cumulative effects in terms of functional complementarity and behavioral guidance. Future research could further investigate the comprehensive impact of multi-facility collaboration on green travel, expanding the perspective from "single cause-single effect" to "multiple causes-collaborative effects."

Finally, the analysis framework of this study primarily focuses on the built environment dimension, without fully considering the impact of green travel management factors. During field research in some neighborhoods and districts, the author observed management measures such as restrictions on motor vehicles and fuel vehicles entering certain areas. These interventions clearly have a significant guiding effect on residents' green travel behavior. Furthermore, this study employed residential-level statistical and analytical methods, failing to fully capture the heterogeneity in travel behavior and facility selection at the household or individual level, which influences residential self-selection and, in turn, travel attitude. The model needs to incorporate less observable and potentially confounding factors (such as weather and social factors) to analyze the impact of variables on other independent variables. Future research could further expand the

analytical dimensions, incorporating green travel management policies and micro-individual behavior factors to reduce inter-variable interference and construct a more comprehensive explanatory framework for green travel mechanisms.

Finally, drawing on Jane Jacobs's statement that cities are "ordered complexities"—one involving dealing simultaneously with a sizeable number of factors which are interrelated into an organic whole—the living circle can be viewed as a complex yet orderly system, urgently in need of further in-depth research and exploration. Meanwhile, Professor Wu Liangyong's concept of "complete community" emphasizes that a true community should be an organic whole, with elements such as housing, education, health, culture, and transportation supporting each other and jointly meeting the daily needs of residents. From this perspective, the living circle is not just a spatially demarcated unit, but a microsystem that supports daily life and green transformation. In future green mobility-oriented upgrades, optimizing facility layout will not only improve the low-carbon conversion efficiency of travel modes but also serve as a key driver in promoting the construction of "complete communities," making living spaces more complete, green, orderly, and sustainable^[189].

REFERENCES

- [1] 杰夫·斯佩克著；欧阳南江，陈明辉，范源萌译. 适宜步行的城市[M]. 北京：中国建筑工业出版社，2016.
- [2] 陆化普,毛其智,李政,贺克斌,帅石金,张希良. 城市可持续交通:问题、挑战和研究方向[J]. 城市发展研究, 2006(5): 91-96.
- [3] 张纯,宁延豪,梁颖.城市建成环境对通勤碳排放的影响——以北京市为例[J].上海城市规划, 2023,(06):18-24.DOI:CNKI:SUN:HCSG.0.2023-06-003.
- [4] 张萍, 李素艳, 黄国洋, 等. 上海郊区大型社区居民使用公共设施的出行行为及规划对策[J]. 规划师, 2013, 29(5): 91-95.
- [5] Oldenburg R. The great good place: Cafes, coffee shops, bookstores, bars, hair salons, and other hangouts at the heart of a community[M]. Da Capo Press, 1999.
- [6] Gehl J. Cities for people[M]. Island press, 2013.
- [7] Jiang Y, Gu P, Chen Y, et al. Modelling household travel energy consumption and CO2 emissions based on the spatial form of neighborhoods and streets: A case study of Jinan, China[J]. Computers, Environment and Urban Systems, 2019, 77: 101134.
- [8] 张杰,杨阳,陈骁,毛其智. 济南市住区建成环境对家庭出行能耗影响研究[J]. 城市发展研究, 2013, 20(7): 83-89.
- [9] 杨阳. 济南市住区建成环境与家庭出行能耗关系的量化研究[D]. 清华大学, 2013.
- [10] 马静,柴彦威,刘志林. 北京市交通碳排放影响机理[J]. 地理学报, 2011, 66(8): 1023-1032.
- [11] United States Department of Transportation. Federal Highway Administration. National Household Travel Survey, 2001: [United States]. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2006-01-18. <https://doi.org/10.3886/ICPSR04047.v1>
- [12] Mertens L, Van Cauwenberg J, Ghekiere A, et al. Does the effect of micro-environmental factors on a street's appeal for adults' bicycle transport vary across different macro-environments? An experimental study[J]. PloS one, 2015, 10(8): e0136715.
- [13] Badiaa Hamama, Maria Paola Repellino, Liu Jian, Michele Bonino. The Processes Behind Community Building and Place Making in Transitional Urban Moments[J]. China City Planning Review, 2019, 28(2): 25-34.
- [14] 中华人民共和国住房和城乡建设部. 城市居住区规划设计标准: GB50180—2018 [S/OL]. (2018-03-13)[2025-08-18]. https://www.mohurd.gov.cn/gongkai/zc/wjk/art/2018/art_17339_238590.html.
- [15] 于一凡.从传统居住区规划到社区生活圈规划[J].城市规划, 2019, 43(5):6.DOI:10.11819/cpr20190504a.
- [16] 罗雪瑶, 柴彦威. “X 分钟城市”理念的概念、内涵与规划方法[J]. 国际城市规划, 2024.
- [17] Rudinger G, Donaghy K, Poppelreuter S (2006) Societal trends, mobility behaviour and sustainable transport in Europe and North America. Available: http://www.ejtir.tudelft.nl/issues/2006_0

- 1/pdf/2006_01_04.pdf.
- [18] Scheiner J, Holz-Rau C. Interrelations between travel mode choice and trip distance. *Transportation Research Part A: Policy and Practice*, 2010, 44(9): 579-588.
- [19] Clifton K J, Krizek K J. The utility of the NHTS in understanding bicycle and pedestrian travel. In: *Proceedings of the National Household Travel Survey Conference*, 2004
- [20] Yang Y. Walking Distance by Trip Purpose and Population Subgroups. *International Journal of Environmental Research and Public Health*, 2012, 9(10): 3268-3280.
- [21] Yu A. Travel behaviour and the 15-min City: Access intensity, neighborhood form, and travel distance. *Sustainable Cities and Society*, 2024, 88: 104474.
- [22] Speck, J. (2018). Walkable city rules: 101 steps to making better places. Island Press.
- [23] 秦棚超. 基于居民低碳出行的 15 分钟生活圈建成环境优化策略研究[D]. 西安建筑科技大学, 2021.
- [24] 肖作鹏,韩来伟,柴彦威. 生活圈规划嵌入国土空间规划的思考[J]. 规划师, 2022, 38(9): 145-151.
- [25] 顾朝林,谭纵波,刘宛,于涛方,韩青,刘合林,戴亦欣,刘志林,郑思齐. 气候变化、碳排放与低碳城市规划研究进展[J]. 城市规划学刊, 2009(3): 38-45.
- [26] 熊健.打造人民城市的理想社区 15 分钟社区生活圈理论的源起,演进与展望[J].时代建筑, 2022(002):000.
- [27] 柴彦威,李彦熙,李春江.时空间行为规划:核心问题与规划手段[J].城市规划,2022,46(12):7-15.
- [28] Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, 15(2), 73–80. <https://doi.org/10.1016/j.tranpol.2007.10.005>
- [29] Litman, T. (2013). The new transportation planning paradigm. *ITE Journal*, 83(6), 20–28.
- [30] Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., ... Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *The Lancet*, 387(10034), 2207–2217. [https://doi.org/10.1016/S0140-6736\(15\)01284-2](https://doi.org/10.1016/S0140-6736(15)01284-2)
- [31] Carstensen, T. A. (2015). Street design and urban cycling: A review of Danish research. *Progress in Planning*, 92, 1–52. <https://doi.org/10.1016/j.progress.2013.03.001>
- [32] Pooley, C. G., Horton, D., Scheldeman, G., Tight, M., Jones, T., Mullen, C., ... Jopson, A. (2010). The role of walking and cycling in sustainable transport systems. Transport Studies Unit, University of Oxford.
- [33] Ville de Paris. (2021). Plan vélo 2021–2026: Pour un Paris 100% cyclable. [Paris Bike Plan 2021–2026: For a 100% Bikeable Paris]. <https://www.paris.fr/pages/paris-100-cyclable-le-nouveau-plan-velo-18345>
- [34] Moreno C. The 15-Minute City: A Solution to Saving Our Time and Our Planet[M]. John Wiley & Sons, 2024.
- [35] 张乾源,朱亚新.唐山市小区规划和住宅建筑设计方案评介[J].建筑学报,1978,(04):1-6+62-63.

- [36] 何德铭,周秀堂,陶松令,等.唐山市河北区居住小区规划[J].同济大学学报,1978,(02):10-18.
- [37] 刘恩华.唐山市新建居住小区规划[J].建筑学报,1987,(04):8-12.
- [38] 富玉林,刘静存.十年复建推陈出新——唐山 51 号居住区规划设计[J].城市规划,1992,(03):19-24+64.
- [39] 程才实.唐山重建的成功与遗憾——追忆唐山大地震后的住宅建设[J].住宅产业,2005,(12):14-17.
- [40] 沈清基,马继武.唐山地震灾后重建规划:回顾、分析及思考[J].城市规划学刊,2008,(04):17-28.
- [41] 陈明玉,甘草,边兰春.城市“双老化”住区识别与类型分析研究——以北京中心城区为例[J].城市发展研究,2022,29(10):87-95.DOI:CNKI:SUN:CSFY.0.2022-10-010
- [42] 中国商务部.关于推进城市 15 分钟便捷生活区建设的意见[EB/OL]. 2021-05-28. 商务部等 12 部门关于推进城市一刻钟便民生活圈建设的意见_国务院部门文件_中国政府网
- [43] 周文竹,阳建强,葛天阳,等.城市用地“3D”发展模式研究——一种基于减少机动化需求的规划理念[J].城市规划,2012,36(10):51-57.DOI:CNKI:SUN:CSGH.0.2012-10-012.
- [44] 吴良镛.住房·完整社区·和谐社会——吴良镛致辞[J].住区, 2011(2):2.DOI:CNKI:SUN:ZUQU.0.2011-02-004.
- [45] Hou, L., & Liu, Y. (2017). Life circle construction in China under the idea of collaborative governance: A comparative study of Beijing, Shanghai and Guangzhou. *Geographical review of Japan series B*, 90(1), 2-16.
- [46] 柴彦威,李彦熙,李春江.时空间行为规划:核心问题与规划手段[J/OL].城市规划:1-9[2023-01-04].<http://kns.cnki.net/kcms/detail/11.2378.TU.20220816.1106.006.html>
- [47] Xiongan makes living circle. http://www.360doc.com/content/21/1129/08/62195212_1006347326.shtml. 2021
- [48] 刘泉、钱征寒、黄丁芳、周晓冰.15 分钟生活圈的空间模式演化特征与趋势[J].城市规划学刊, 2020(6):8.
- [49] 商志原.居住区发展概述[J].城市规划研究, 1981(2):12-43.
- [50] Perry, C. (1929). *The Neighborhood Unit, a scheme of arrangement for the family-life community*, New York.
- [51] Gibberd, F. (1953). *Town design*. Architectural press.
- [52] Calthorpe, P. (1993). *The Next American Metropolis: Ecology, Community, and the American Dream*. Princeton Architectural Press.
- [53] Duany, A. (2000). *Suburban nation: the rise of sprawl and the decline of the American dream*. North point.
- [54] Architectural Society of China. (2017). *Architectural Design Data Collection* (3rd edition). Volume 2, Residence. Beijing: China Architecture & Building Press.
- [55] 杨辰,张宁馨.邻里单位—居住小区—社区生活圈从上海曹杨新村看当代中国住区规划理论的演变[J].时代建筑,2022,(02):30-37.DOI:10.13717/j.cnki.ta.2022.02.030.
- [56] 郑正,王仲谷.深圳白沙岭高层居住区[J].时代建筑,1985,(01):48-51.DOI:CNKI:SUN:SDJZ.0.

- 1985-01-014.
- [57] 蔡镇钰.上海曲阳新村居住区的规划设计[J].住宅科技,1986,(01):25-29.DOI:CNKI:SUN:ZZKJ.0.1986-01-015.
- [58] 蔡镇钰.上海曲阳新村公建配套设计[J].建筑学报,1984,(03):42-46.DOI:CNKI:SUN:JZXB.0.1984-03-013.
- [59] 张晓荣,杨辉.城市社区生活圈低碳更新模式——基于设施布局形态类型的探讨[J].城市规划,2025,49(03):43-51+60.DOI:CNKI:SUN:CSGH.0.2025-03-003.
- [60] 朱玮,翟宝昕.生活圈视角下家庭生活行为的特征及空间评价——以上海市为例[J].上海城市规划,2024,(06):131-138.DOI:CNKI:SUN:HCSG.0.2024-06-019.
- [61] Staricco, L. (2022). 15-, 10-or 5-minute city? A focus on accessibility to services in Turin, Italy. *Journal of urban mobility*, 2, 100030.
- [62] 赵鹏军,罗佳,胡昊宇. 基于大数据的生活圈范围与服务设施空间匹配研究[J]. 地理科学进展, 2021, 40(4): 541-553.
- [63] Zhao Pengjun, Luo Jia, Hu Haoyu. Spatial match between residents' daily life circle and public service facilities[J]. *Progress in Geography*, 2021, 40(4): 541-553.
- [64] 左进, 孟蕾, 曾韵. 面向智慧化建设的社区生活圈配套设施布局优化[M]. 北京: 中国建筑工业出版社, 2020.
- [65] Zhang E, Hou J, Long Y. The form of China's urban commercial expansion in the digital era[J]. *Nature Cities*, 2025.
- [66] 龙瀛,赵健婷,李双金,等.中国主要城市街道步行指数的大规模测度[J].新建筑,2018,(03):4-8. DOI:CNKI:SUN:XJZJ.0.2018-03-002.
- [67] Zhang, S., Liu, N., Ma, B., & Yan, S. (2023). The effects of street environment features on road running: An analysis using crowdsourced fitness tracker data and machine learning. *Environment and Planning B: Urban Analytics and City Science*, 51(2), 529-545. <https://doi.org/10.1177/23998083231185589> (Original work published 2024)
- [68] 张萍. 城市郊区保障性社区居民活动行为与公共设施布局研究[M]. 上海: 同济大学出版社, 2019.07.
- [69] 王承慧. 与城市联动的社区生活圈研究与规划[M]. 南京: 东南大学出版社, 2024.
- [70] Spence J C, Lee R E. Toward a comprehensive model of physical activity. *Exercise and Sport Sciences Reviews*, 2003, 31(4): 195-203.
- [71] 温煦,何晓龙. 建成环境对交通性体力活动的影响[J]. 体育与科学, 2014, 35(1): 41-45.
- [72] Alfonzo M A. To walk or not to walk? The hierarchy of walking needs[J]. *Environment and Behavior*, 2005, 37(6): 808-836.
- [73] Jeff Speck; *Pedestrian Cities: Saving America by Creating Vibrant City Centers* Translated by Ouyang Nanjiang, Chen Minghui, Fan Yuanmeng, 2016
- [74] Kerr J, Emond J A, Badland H, et al. Perceived neighborhood environmental attributes[J]. *Environmental Health Perspectives*, 2016, 124(3): 290-298.
- [75] Garrard J, Rose G, Lo S K. Promoting transportation cycling for women[J]. *Preventive Medicine*

REFERENCES

- ne, 2008, 46(1): 55-59.
- [76] Buehler R, Pucher J. COVID-19 impacts on cycling, 2019–2020[J]. *Transport Reviews*, 2021, 41(4): 393-400.
- [77] Boarnet M, Crane R. *Travel by Design: The Influence of Urban Form on Travel*[M]. Oxford University Press, 2001.
- [78] 安睿,刘圆圆,韩军红,张兴宇. 基于 Logistic 模型的城市慢行交通出行者特性研究[J]. *交通运输研究*, 2015, 1(6): 26-32.
- [79] 于沛洋,石飞,索南曲珍卓玛,郑颖. 基于开放数据的城市公共交通可达性模型构建方法[J]. *现代城市研究*, 2017(12): 2-10.
- [80] 吕雄鹰. 上海及邻沪地区城镇圈公共交通一体化发展思考[J]. *交通与港航*, 2018, 5(4): 26-32.
- [81] 周荣,侯威震,曾晨曦,张绍成,柴炳阳.不同 GPS 掩星电离层剖面产品相关性分析[J].*测绘通报*,2019(11):31-38+73.DOI:10.13474/j.cnki.11-2246.2019.0347.
- [82] 王德,傅英姿. 手机信令数据助力上海市社区生活圈规划[J]. *上海城市规划*, 2019(6): 23-29.
- [83] 黄慧明,周岱霖,王烨. 基于居住形态类型的社区生活圈空间组织模式研究[J]. *城市规划学刊*, 2021(2): 94-101.
- [84] 孙道胜,柴彦威,张艳. 社区生活圈的界定与测度:以北京清河地区为例[J]. *城市发展研究*, 2016, 23(9): 1-9.
- [85] 傅英姿,王德. 上海市典型住宅区生活空间结构模式研究[J]. *地理科学进展*, 2021, 40(4): 565-579.
- [86] Salonen M, Broberg A, Kyttä M, et al. Do suburban residents prefer the fastest or low-carbon travel modes?[J]. *Applied Geography*, 2014, 53: 438-448.
- [87] Zhao C, Nielsen T A S, Olafsson A S, et al. Urban form, demographic and socio-economic correlates of walking, cycling, and e-biking[J]. *Transport Policy*, 2018, 64: 102-112.
- [88] 马静,柴彦威,刘志林.基于居民出行行为的北京市交通碳排放影响机理[J].*地理学报*,2011,66(08):1023-1032.
- [89] Zhang J, Chai X, He X P, et al. Fluorogenic probes for disease-relevant enzymes[J]. *Chemical Society Reviews*, 2019, 48(2): 683-722.
- [90] Kärmeniemi M, Lankila T, Ikäheimo T, et al. The built environment as a determinant of physical activity: a systematic review of longitudinal studies and natural experiments[J]. *Annals of behavioral medicine*, 2018, 52(3): 239-251.
- [91] 彼得·罗,关成贺.实现中国城市社区、街区和规划布局之间的平衡[J].*时代建筑*,2016,(06):29-33.DOI:10.13717/j.cnki.ta.2016.06.006.
- [92] Brainard J, Cooke R, Lane K, et al. Age, sex and other correlates with active travel walking and cycling in England: Analysis of responses to the Active Lives Survey 2016/17[J]. *Preventive Medicine*, 2019, 123: 225-231.
- [93] Kärmeniemi M, Lankila T, Ikäheimo T, et al. The built environment as a determinant of physical activity: a systematic review of longitudinal studies and natural experiments[J]. *Annals of behavioral medicine*, 2018, 52(3): 239-251.

REFERENCES

- vioral medicine, 2018, 52(3): 239-251.
- [94] Gim T H T. The relationships between land use measures and travel behavior[J]. *Transportation Planning and Technology*, 2013, 36(5): 413-434.
- [95] Javaid A, Creutzig F, Bamberg S. Determinants of low-carbon transport mode adoption[J]. *Environmental Research Letters*, 2020, 15(10): 103002.
- [96] 吴娇蓉,华陈睿,王达琳. 公共设施布置与慢行出行行为的关系[J]. *城市规划*, 2014, 38(7): 57-60+67.
- [97] 陈泳,严佳. 步行活动与轨道交通的共生[J]. *上海城市规划*, 2017(1): 1-8.
- [98] Ding C, Cao X J, Næss P. Applying gradient boosting decision trees to examine non-linear effects of the built environment on driving distance in Oslo[J]. *Transportation Research Part A*, 2018, 110: 107-117.
- [99] Ewing R, Hamidi S, Grace J B. Compact development and VMT[J]. *Environment and Planning B*, 2016, 43(4): 737-755.
- [100] Mecredy G, Pickett W, Janssen I. Street connectivity and physical activity in Canadian youth[J]. *IJERPH*, 2011, 8(8): 3333-3350.
- [101] Southworth M. Designing the walkable city[J]. *J. Urban Planning and Development*, 2005, 131(4).
- [102] Green C G, Klein E G. Promoting active transportation as a partnership[J]. *Public Health Reports*, 2011, 126(1_suppl): 41-49.
- [103] Arsenio E, Dias J V, Lopes S A, et al. Assessing the market potential of electric bicycles[J]. *ETRR*, 2018, 10(1): 1-9.
- [104] Gebhart K, Noland R B. The impact of weather conditions on bikeshare trips[J]. *Transportation*, 2014, 41(6): 1205-1225.
- [105] Saneinejad S, Roorda M J, Kennedy C. Modelling the impact of weather conditions on active transportation[J]. *Transport Research D*, 2012, 17(2): 129-137.
- [106] Saelens B E, Sallis J F, Frank L D, et al. Neighborhood environment and psychosocial correlates of adults' physical activity[J]. *Med Sci Sports Exerc*, 2012, 44(4): 637-646.
- [107] Perchoux C, Kestens Y, Brondeel R, et al. Accounting for the daily locations visited[J]. *Preventive Medicine*, 2015, 81: 142-149.
- [108] Cranney L, Phongsavan P, Kariuki M, et al. Impact of an outdoor gym on park users' physical activity[J]. *Health & Place*, 2016, 37: 26-34.
- [109] Cervero R, Denman S, Jin Y. Network design and bicycle commuting[J]. *Transport Policy*, 2019, 74: 153-164.
- [110] Hampshire R C, Marla L. An analysis of bike sharing usage[C]. *TRB 91st Annual Meeting*, 2012.
- [111] El-Assi W, Salah Mahmoud M, Nurul Habib K. Effects of built environment and weather on bike sharing demand[J]. *Transportation*, 2017, 44(3): 589-613.
- [112] 莫海彤,魏宗财. 居住环境品质优化下的中国社区规划演变研究[J]. *南方建筑*, 2021(5):

REFERENCES

- 38-43.
- [113] 曾小利. 基于就业区分异的深圳居民通勤行为特征及影响因素分析[D]. 深圳大学, 2019.
- [114] Næss P. Residential self-selection and appropriate control variables[J]. *Transport Reviews*, 2009, 29(3): 293-324.
- [115] Næss P. Residential location, travel, and energy use in Hangzhou[J]. *Journal of Transport and Land Use*, 2010, 3(3): 27-59.
- [116] Næss P. Residential location, transport rationales and daily-life travel behaviour[J]. *Progress in Planning*, 2013, 79: 1-50.
- [117] 北京交通发展研究院, 2021. 2021 北京市交通发展年度报告[R]. 北京: 北京交通发展研究院.
- [118] Lai, Y., Li, J., Zhang, J., Yan, L., & Liu, Y. (2022). Do vibrant places promote active living? Analyzing local vibrancy, running activity, and real estate prices in Beijing. *International Journal of Environmental Research and Public Health*, 19(24), 16382.
- [119] Huff D L. Determination of Intra-Urban Retail Trade Areas”, Real Estate Research Program, Graduate School of Business[J]. Los Angeles, CA", UCLA, 1963.
- [120] 石川栄耀. 大東京地方計画方法論[M]//佚名. 人口問題資料第四十輯 第三回人口問題全国協議会報告書. 東京: 刀江書院, 1941: 409-420
- [121] 杉浦芳夫. 幾何学の帝国: わが国における中心地理論受容前夜[J]. *地理学評論*, 1996, 69 (11) : 857-878
- [122] Nobuo Takahashi. A study on time-space behavior in Japanese living space[J]. *Human Geography*, 1987, 39(4): 295-318.
- [123] 孙道胜,柴彦威.日本的生活圈研究回顾与启示[J].*城市建筑*,2018,(36):13-16.DOI:10.19892/j.cnki.csjz.2018.36.003.
- [124] Christaller W. Central places in southern Germany[M]. 1966.
- [125] Moreno C. The 15 minutes city for a new chrono-urbanism[EB/OL]. 2019-06-20.
- [126] Allam Z, Moreno C, Chabaud D, et al. Proximity-Based Planning and the “15-Minute City”[M]. Springer, 2021.
- [127] Moreno C, Allam Z, Chabaud D, et al. Introducing the “15-Minute City”[J]. *Smart Cities*, 2021, 4(1): 93-111.
- [128] Paris. Paris ville du quart d’heure ou le pari de la proximité[EB/OL]. 2022-05-23.
- [129] Cervero R, Kockelman K. Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment*, 1997, 2(3): 199-219. Capes Periodicals +3Massachusetts Institute of Technology+3SCIRP+3
- [130] Ewing R, Cervero R. Travel and the built environment: a synthesis. *Transportation Research Record*, 2001, 1780: 87-114.
- [131] Ewing R, Cervero R. Travel and the built environment: a meta-analysis. *Journal of the American Planning Association*, 2010, 76(3): 265-294.

REFERENCES

- [132] Handy S. Regional versus local accessibility: Implications for nonwork travel[J]. 1993.
- [133] Ewing R, Bartholomew K. Pedestrian- and Transit-Oriented Design[M]. Urban Land Institute, 2013.
- [134] Buehler R, Pucher J. Cycling for Sustainable Cities[M]. MIT Press, 2021.
- [135] ZHANG S, YUAN C, CHEN T. A cross-scale indicator framework for the study of annual stability of land surface temperature in different land uses[J/OL]. Sustainable cities and society, 2024, 116: 105936. DOI:10.1016/j.scs.2024.105936.
- [136] SHAPLEY L S. A value for n-person games // KUHN H W, TUCKER A W, eds. *Contributions to the Theory of Games II*. Princeton: Princeton University Press, 1953: 307-317.
- [137] CHEN T, GUESTRIN C. XGBoost: A scalable tree boosting system // *Proceedings of the 2nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (KDD '16)*. New York: Association for Computing Machinery, 2016: 785-794. DOI: 10.1145/2939672.2939785.
- [138] BREIMAN L. Random forests. *Machine Learning*, 2001, 45(1): 5-32.
- [139] Friedman JH (2001) Greedy function approximation: A gradient boosting machine. *Annals of Statistics* 29(5):1189–1232.)
- [140] JAIN A K, MURTY M N, FLYNN P J. Data clustering: A review[J]. *ACM Computing Surveys*, 1999, 31(3): 264-323. DOI: 10.1145/331499.331504.
- [141] Murtagh & Contreras, 2012, WIREs Data Mining Knowl Discov 2011. doi: 10.1002/widm.53
- [142] Tan, Steinbach, Kumar, Introduction to Data Mining, McGraw Hill 200
- [143] F. Pedregosa, G. Varoquaux, A. Gramfort, V. Michel, B. Thirion, O. Grisel, M. Blondel, P. Prettenhofer, R. Weiss, V. Dubourg, Scikit-learn: machine learning in Python, *J. Mach. Learn. Res.* 12 (2011) 2825–28306
- [144] Zhang Y, Du L, Liu J. Identifying the reuse patterns of coal mining subsidence areas: A case-study of Jixi City (China)[J]. *Land Degradation & Development*, 2021, 32(17): 4858-4870.
- [145] 上海市城乡建设和交通发展研究院. 2015. 上海市第五次综合交通调查成果报告[R]. 上海.
- [146] Moreno, Carlos. (2022). Living in Proximity in a Living City. *Glocalism*. 10.12893/gjcpi.2021.3.8.
- [147] Doyle S, Kelly-Schwartz A, Schlossberg M, et al. Active community environments and health: the relationship of walkable and safe communities to individual health[J]. *Journal of the American planning association*, 2006, 72(1): 19-31.
- [148] Ewing R, Meakins G, Hamidi S, et al. Relationship between urban sprawl and physical activity, obesity, and morbidity—Update and refinement[J]. *Health & place*, 2014, 26: 118-126.
- [149] 姜洋,何东全,ZEGRAS Christopher.城市街区形态对居民出行能耗的影响研究[J].*城市交通*, 2011, 9(4):10.DOI:10.3969/j.issn.1672-5328.2011.04.003.
- [150] Luo S, Zhen F, Yin Q. How built environment influence public bicycle usage: Evidence from

- m the bicycle sharing system in Qiaobei Area, Nanjing[J]. *Scientia Geographica Sinica*, 2018, 38(3): 332-341.
- [151] Arsenio E, Dias J V, Lopes S A, et al. Assessing the market potential of electric bicycles and ICT for low carbon school travel: a case study in the Smart City of ÁGUEDA[J]. *European Transport Research Review*, 2018, 10(1): 13.
- [152] Lai, Y., & Kontokosta, C. E. (2018). Quantifying place: Analyzing the drivers of pedestrian activity in dense urban environments. *Landscape and Urban Planning*, 180, 166-178.
- [153] 张纯,黎雪莹.多维度多尺度的 TOD 理论趋势及在发展中国家应用实践[J/OL].*国际城市规划*,1-23[2025-10-04].<https://doi.org/10.19830/j.upi.2023.156>.
- [154] 王承慧,章毓婷.大型保障房社区公共设施供给机制优化研究[J].*城市规划学刊*,2017,(02):96-103.DOI:10.16361/j.upf.201702011.
- [155] 李颖,颜婷,曾艺元,等.行为量化分析视角下的公共服务设施有效使用评估研究[J].*规划师*, 2019(2):7.DOI:CNKI:SUN:GHSL.0.2019-02-011.
- [156] Chen X, He J, Han M, et al. Understanding the impacts of street greening patterns and wind directions on the dispersion of fine particles[J]. *Science of The Total Environment*, 2024, 953: 176044.
- [157] Klarqvist B. A space syntax glossary[J]. *NA*, 2015, 6(2).
- [158] Liu Y, Yang D, Timmermans HJP, et al. Analysis of the impact of street-scale built environment design near metro stations on pedestrian and cyclist road segment choice: A stated choice experiment[J]. *Journal of transport geography*, 2020, 82: 102570.
- [159] Koohsari MJ, Owen N, Cerin E, et al. Walkability and walking for transport: characterizing the built environment using space syntax[J]. *International Journal of Behavioral Nutrition and Physical Activity*, 2016, 13(1): 121.
- [160] Guzman LA, Peña J, Carrasco J A. Assessing the role of the built environment and sociodemographic characteristics on walking travel distances in Bogotá[J]. *Journal of transport geography*, 2020, 88: 102844.
- [161] Lu Y. The association of urban greenness and walking behavior: Using google street view and deep learning techniques to estimate residents' exposure to urban greenness[J]. *International journal of environmental research and public health*, 2018, 15(8): 1576.
- [162] Liu J, Zhang Y, Mao J. Social Enterprises and Their Role in Revitalizing Shrinking Cities—A Case Study on Shimizusawa of Japan[J]. *Land*, 2023, 12(12): 2146.
- [163] LIANG Y, GAO S, CAI Y. Calibrating the dynamic Huff model for business analysis using location big data[J/OL]. *Transactions in GIS*, 2020, 24(3): 681-703. DOI:10.1111/tgis.12624.
- [164] Teixeira F M, Derudder B. Spatio-temporal dynamics in airport catchment areas: The case of the New York Multi Airport Region[J]. *Journal of Transport Geography*, 2021, 90: 102916.
- [165] 丁亮,钮心毅,宋小冬.基于个体移动轨迹的多中心城市引力模型验证[J].*地理学报*, 2020, 75(2):18.DOI:10.11821/dlxb202002005.
- [166] Alexander C. A city is not a tree[J]. *Ekistics*, 1965, 139(344-348): 490.

- [167] Davies R L. Marketing Geography: with special reference to retailing. [M] London: Methuen, 1976.132
- [168] Davies R L. Structural model of retail distribution: analogies with settlement and land-use theories.
- [169] 仵宗卿,柴彦威,戴学珍,等.购物出行空间的等级结构研究——以天津市为例[J].地理研究,2001,(04):479-488.DOI:CNKI:SUN:DLYJ.0.2001-04-013.
- [170] Freeman L C. Segregation in social networks[J]. Sociological Methods & Research, 1978, 6(4): 411-429.
- [171] Opsahl, T., Agneessens, F., & Skvoretz, J. (2010). Node centrality in weighted networks: Generalizing degree and shortest paths. Social Networks, 32(3), 245–251
- [172] 丁亮,钮心毅,宋小冬.上海中心城区商业中心空间特征研究[J].城市规划学刊,2017,(01): 63-70.DOI:10.16361/j.upf.201701008.
- [173] 傅英姿,王德.上海市典型住宅区生活空间结构模式研究[J].地理科学进展,2021,40(4): 565-579.
- [174] 王德,王灿,谢栋灿,等.基于手机信令数据的上海市不同等级商业中心商圈的比较——以南京东路、五角场、鞍山路为例[J].城市规划学刊,2015(3):11.DOI:10.16361/j.upf.201503007.
- [175] 柴彦威,翁桂兰,沈洁,等.基于居民购物消费行为的上海城市商业空间结构研究[J].地理研究,2008,27(4):897-906.DOI:10.3321/j.issn:1000-0585.2008.04.018.
- [176] 朱玮,翟宝昕.生活圈视角下家庭生活行为的特征及空间评价——以上海市为例[J].上海城市规划,2024(6):131-138.
- [177] 朱玮,梁雪媚,张安婕.街道商业空间整治对居民生活的影响——以上海市5条街道为例[J].上海城市规划,2023(4):92-100.DOI:10.11982/j.supr.20230414.
- [178] 朱玮,李博涵.上海郊区城镇零售商业空间的服务特征及需求规律[J].城市规划学刊,2021,(01):90-96.DOI:10.16361/j.upf.202100011.
- [179] 周素红,林耿,闫小培.广州市消费者行为与商业业态空间及居住空间分析[J].地理学报,2008,(04):395-404.DOI:CNKI:SUN:DLXB.0.2008-04-012.
- [180] 龙瀛,周垠.街道活力的量化评价及影响因素分析——以成都为例[J].新建筑,2016,(01): 52-57.DOI:CNKI:SUN:XJZJ.0.2016-01-010.
- [181] 张译心,杜立柱,杜昊霖,等.开放式老旧小区更新利益冲突与规划应对[J].住宅科技,2022,42(10):13-19.DOI:10.13626/j.cnki.hs.2022.10.004.
- [182] 来源,胡安妮.基于人居活动数据的城市分析——纽约市实践经验及其城市人因工程学启示[J].世界建筑,2023,(07):10-15.DOI:10.16414/j.wa.2023.07.015.
- [183] 刘健,张译心.15分钟城市:巴黎建设绿色便民城市的实践[J].北京规划建设,2023,(04): 24-29.DOI:CNKI:SUN:GHJS.0.2023-04-040.
- [184] Paris. La ville du quart d'heure en images [EB/OL]. (2022-06-13) [2022-06-13] <https://www.paris.fr/pages/la-ville-du-quart-d-heure-en-images-15849>.
- [185] 胡杰,黄经南,黄瑾,刘沛.多中心城市空间结构与家庭碳排放关系研究[J].规划师,2014,

REFERENCES

- 30(11): 87-92.
- [186] Zhang Y, Yan S, Liu J, et al. Popularity influence mechanism of creative industry parks: A semantic analysis based on social media data[J]. *Sustainable Cities and Society*, 2023, 90: 104384.
- [187] 王承慧,邱建维,瞿嘉琳,等.社区中心空间类型和服务效益: 对社区生活圈规划的启示[J].*现代城市研究*,2022,(08):43-50.
- [188] 杨俊宴,吴浩,郑屹.基于多源大数据的城市街道可步行性空间特征及优化策略研究——以南京市中心城区为例[J].*国际城市规划*,2019,34(05):33-42.DOI:CNKI:SUN:GWCG.0.2019-05-005.
- [189] Nieuwenhuijsen M J. New urban models for sustainable, liveable and healthier cities post covid-19[J]. *Environment International*, 2021, 157: 106850.

APPENDIX A PLANNINGS OF TANGSHAN

1 The 15-Minute Living Circle Construction Plan

Table A.1 Reference Standards for Living circle Planning and Facility Layout Tiers in Tangshan

Serial Number	Facility Name	Scale	Service Content	Service Radius	Reference standards, the	x-minute neighborhood (walking)
		Floor Area (m ²)	Site Area (m ²)			
1	Neighborhood Commercial Center (Supermarket)	1500~3000	——	(1) Should be centrally located within the residential quarter, at a relatively central position; (2) The service radius should not exceed 1000 meters.	Opinions of Hebei Province on Strengthening the Planning, Construction, and Management of Non-operational Public Facilities in Urban Residential Communities	15-Minute Neighborhood

APPENDIX A PLANNINGS OF TANGSHAN

2	Vegetable markets (Community Vegetable markets)	The operating area for a vegetable market shall be no less than 500 m ² per facility; for community vegetable markets, 50–100 m ² per thousand people, generally not less than 500 m ² .	——	Operating with multiple independent vendors, the venue retails staple and non-staple foods through leased stalls and dedicated booths, specializing in fruits, vegetables, meat, poultry, eggs and their products, aquatic products, dairy products, bean products, dried foods, condiments, grains, oils and their products.	The service radius of vegetable markets should not exceed 500m, with parking areas for motor vehicles and non-motor vehicles to be provided; in areas where conditions do not permit, the establishment of community vegetable markets should be considered to serve the population within the living circle.	<i>Opinions of Hebei Province on Strengthening the Planning, Construction, and Management of Non-Profit Public Facilities in Urban Residential Communities; Specifications for the Establishment and Management of Community Vegetable markets (Farmers' Markets) in Beijing</i>	10-Minute Neighborhood

APPENDIX A PLANNINGS OF TANGSHAN

Table A.1 Reference Standards for Living circle Planning and Facility Layout Tiers in Tangshan (Continued)

Serial Number	Facility Name	Scale		Service Content	Service Radius	Reference standards, the	x-minute neighborhood (walking)
3	Supermarket	200~1999	——	Retailing of daily necessities for residents	Service radius should not exceed 300m	Scale reference: <i>Classification of Retail Formats GBT18106-2021</i> (small supermarket); Service radius reference: <i>Standard of Urban Residential quarter Planning and Design GB50180-2018</i> <i>Opinions of Hebei Province on Strengthening the Planning, Construction, and Management of Non-Profit Public Facilities in Urban Residential Communities</i>	5-Minute Neighborhood
4	Convenience Store	50~100	——	Retailing of daily necessities for residents	One facility per 1,000–3,000 people		5-Minute Neighborhood



Figure A.1 Peirenli Community 5-Minute Living Circle Construction Plan

2 The Master Plan of Tangshan

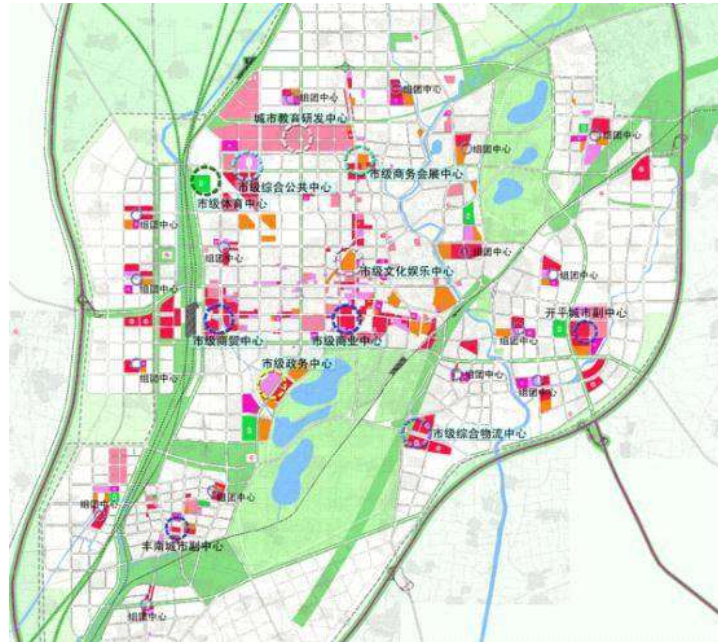


Figure A.2 Tangshan General Planning Functional Structure Diagram

唐山市国土空间总体规划（2021—2035年）

34. 中心城区公共服务设施体系规划图

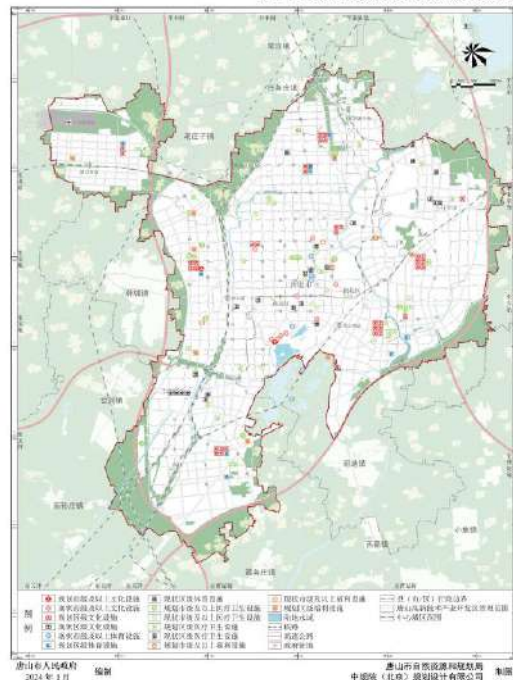


Figure A.3 Tangshan Central Urban Space Structure Planning Diagram and Tangshan Central Urban Public Service Facilities System Planning Map

APPENDIX B LIVING CIRCLES RANGES

1 Details of living circle delineation method

Python code for obtaining the distance and duration fields of the end point.

Try:

```
s = requests.Session()
s.mount('http://', HTTPAdapter(max_retries=3))
r = requests.get(url, param, timeout=(3, 7))
res = r.json()
print(res)

duration = int(res['route']['paths'][0]['time']) # Extract the time field
distance = int(res['route']['paths'][0]['distance']) # Extract the distance field
```

RideRoute 对象

属性	类型	说明
distance	Number	起点到终点总步行距离, 单位: 米
time	Number	步行时间预计, 单位: 秒
rides	Array.< RideStep >	路段列表, 以道路名称作为分段依据, 将整个骑行导航方案分隔成若干路段

Figure B.1 Route Planning Function and Field Retrieval Example (Source: Gaode Map Developer Platform)

APPENDIX B LIVING CIRCLES RANGES

	name_start	name_end	lng_x_end	lat_y_end	lng_x_star	lat_y_star	▲
1	p101center	142	118.095033999999998	39.642640000000000	118.146393000000003	39.647550000000003	
2	p101center	141	118.095048000000006	39.643540999999999	118.146393000000003	39.647550000000003	
3	p101center	140	118.095061999999999	39.644441000000000	118.146393000000003	39.647550000000003	
4	p101center	139	118.095076000000006	39.645341999999999	118.146393000000003	39.647550000000003	
5	p101center	138	118.095089999999999	39.646242999999998	118.146393000000003	39.647550000000003	
6	p101center	137	118.095105000000004	39.647143999999997	118.146393000000003	39.647550000000003	
7	p101center	136	118.095118999999997	39.648045000000003	118.146393000000003	39.647550000000003	
8	p101center	135	118.095133000000004	39.648946000000002	118.146393000000003	39.647550000000003	
9	p101center	134	118.095146999999997	39.649847000000001	118.146393000000003	39.647550000000003	
10	p101center	133	118.095162000000002	39.650748000000000	118.146393000000003	39.647550000000003	
11	p101center	132	118.095175999999995	39.651648000000002	118.146393000000003	39.647550000000003	
12	p101center	131	118.095190000000002	39.652549000000000	118.146393000000003	39.647550000000003	
13	p101center	130	118.095203999999995	39.653449999999999	118.146393000000003	39.647550000000003	
14	p101center	238	118.096114000000000	39.637224000000003	118.146393000000003	39.647550000000003	
15	p101center	237	118.096127999999993	39.638123999999998	118.146393000000003	39.647550000000003	
16	p101center	236	118.096142000000000	39.639024999999997	118.146393000000003	39.647550000000003	
17	p101center	235	118.096155999999993	39.639926000000003	118.146393000000003	39.647550000000003	
18	p101center	234	118.096170000000001	39.640827000000002	118.146393000000003	39.647550000000003	
19	p101center	233	118.096185000000006	39.641728000000001	118.146393000000003	39.647550000000003	
20	p101center	232	118.096198999999999	39.642628999999999	118.146393000000003	39.647550000000003	
21	p101center	231	118.096213000000006	39.643529999999998	118.146393000000003	39.647550000000003	
22	p101center	230	118.096226999999999	39.644430000000000	118.146393000000003	39.647550000000003	
23	p101center	229	118.096242000000004	39.645330999999999	118.146393000000003	39.647550000000003	
24	p101center	228	118.096255999999997	39.646231999999998	118.146393000000003	39.647550000000003	
25	p101center	227	118.096270000000004	39.647132999999997	118.146393000000003	39.647550000000003	
26	p101center	226	118.096283999999997	39.648034000000003	118.146393000000003	39.647550000000003	
27	p101center	225	118.096298000000004	39.648935000000002	118.146393000000003	39.647550000000003	
28	p101center	224	118.096312999999995	39.649836000000001	118.146393000000003	39.647550000000003	
29	p101center	223	118.096327000000002	39.650736000000002	118.146393000000003	39.647550000000003	
30	p101center	222	118.096340999999995	39.651637000000001	118.146393000000003	39.647550000000003	

Figure B.2 Coordinates of Some Grid Points and Destination Points of the Residential
quarter Centroid

APPENDIX B LIVING CIRCLES RANGES

	name_start	name_end	lng_x_end	lat_y_end	duration	distance	lng_x_star	lat_y_star	minute2
1	p101center	130	118.095203999999995	39.653449999999999	1730	5675	118.146393000000003	39.647550000000003	28.83
2	p101center	131	118.095190000000002	39.652549000000000	1730	5675	118.146393000000003	39.647550000000003	28.83
3	p101center	132	118.095175999999995	39.651648000000002	1898	6236	118.146393000000003	39.647550000000003	31.63
4	p101center	133	118.095162000000002	39.650748000000000	2113	6885	118.146393000000003	39.647550000000003	35.22
5	p101center	134	118.095146999999997	39.649847000000001	2066	6754	118.146393000000003	39.647550000000003	34.43
6	p101center	135	118.095133000000004	39.648946000000002	2064	6749	118.146393000000003	39.647550000000003	34.40
7	p101center	136	118.095118999999997	39.648045000000003	2179	7132	118.146393000000003	39.647550000000003	36.32
8	p101center	137	118.095105000000004	39.647143999999997	1810	5850	118.146393000000003	39.647550000000003	30.17
9	p101center	138	118.095089999999999	39.646242999999998	2094	6874	118.146393000000003	39.647550000000003	34.90
10	p101center	139	118.095076000000006	39.645341999999999	2064	6774	118.146393000000003	39.647550000000003	34.40
11	p101center	140	118.095061999999999	39.644441000000000	2035	6676	118.146393000000003	39.647550000000003	33.92
12	p101center	141	118.095048000000006	39.643540999999999	2004	6575	118.146393000000003	39.647550000000003	33.40
13	p101center	142	118.095033999999998	39.642640000000000	1975	6477	118.146393000000003	39.647550000000003	32.92
14	p101center	214	118.096455000000006	39.658844000000002	1778	5838	118.146393000000003	39.647550000000003	29.63
15	p101center	215	118.096440999999999	39.657944000000001	1858	6107	118.146393000000003	39.647550000000003	30.97
16	p101center	216	118.096427000000006	39.657043000000002	1773	5789	118.146393000000003	39.647550000000003	29.55
17	p101center	217	118.096412000000001	39.656142000000003	1737	5690	118.146393000000003	39.647550000000003	28.95
18	p101center	218	118.096397999999994	39.655240999999997	1704	5592	118.146393000000003	39.647550000000003	28.40
19	p101center	219	118.096384000000000	39.654339999999999	1760	5775	118.146393000000003	39.647550000000003	29.33
20	p101center	220	118.096369999999993	39.653438999999999	1647	5400	118.146393000000003	39.647550000000003	27.45
21	p101center	221	118.096355000000003	39.652538000000000	1730	5675	118.146393000000003	39.647550000000003	28.83
22	p101center	222	118.096340999999995	39.651637000000001	2113	6885	118.146393000000003	39.647550000000003	35.22
23	p101center	223	118.096327000000002	39.650736000000002	2113	6885	118.146393000000003	39.647550000000003	35.22
24	p101center	224	118.096312999999995	39.649836000000001	2107	6868	118.146393000000003	39.647550000000003	35.12
25	p101center	225	118.096298000000004	39.648935000000002	2091	6823	118.146393000000003	39.647550000000003	34.85
26	p101center	226	118.096283999999997	39.648034000000003	2235	7287	118.146393000000003	39.647550000000003	37.25
27	p101center	227	118.096270000000004	39.647132999999997	1778	5762	118.146393000000003	39.647550000000003	29.63
28	p101center	228	118.096255999999997	39.646231999999998	1778	5762	118.146393000000003	39.647550000000003	29.63
29	p101center	229	118.096242000000004	39.645330999999999	1815	5889	118.146393000000003	39.647550000000003	30.25
30	p101center	230	118.096226999999999	39.644430000000000	1796	5836	118.146393000000003	39.647550000000003	29.93

Figure B.3 The distance, duration, and minute2 of some fishing net array endpoints obtained

2 Method verification: using real-world trajectories and mobile data

Two methods were used to verify the 15-minute walking living circle defined in the previous section: the real-world trajectory method and the mobile data method.

● Method 1: Real-World Trajectory Method

This method verifies the accuracy of the living circle range by collecting 16 walking trajectories. The starting points are within the residential land boundary, and the endpoints fall within the two types of living circle ranges, with the travel times being 15 minutes or less.

● Method 2: Mobile Data Method

This method uses mobile data to visualize residents' travel behavior and verify the accuracy of the living circle range. The study selected 34,014 mobile travel records within the TC101 boundary from the Smart Footprint data provided by China Unicom for the

period from October 1 to 31, 2020. To identify travel modes (see section 1.5.1 for the data and travel mode identification method), Gaode Map API was used to obtain travel times for walking, cycling, electric bikes, buses, and cars. The time differences between these travel modes and the mobile data were compared, with the closest matching mode being considered the actual travel mode. In total, 1,898 walking trips were identified. Further filtering was applied to select walking trips with a travel time of less than 15 minutes, yielding 31 valid data points to verify the accuracy of the 15-minute walking living circle definition.

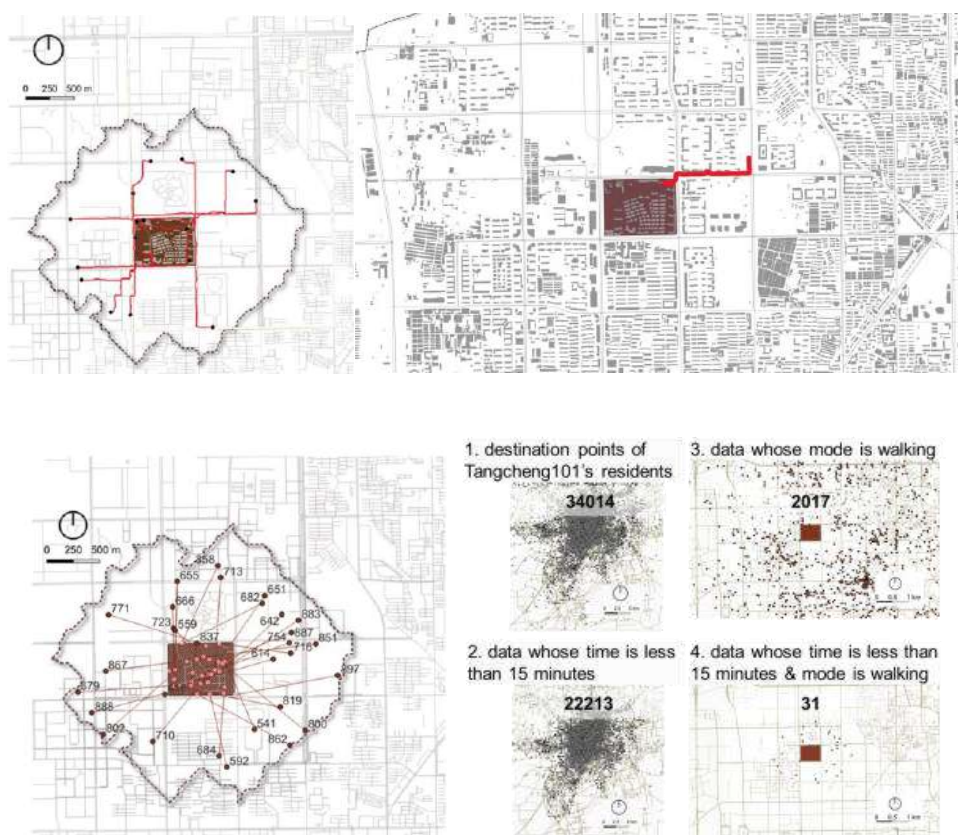


Figure B.4 Verification of the 15-Minute Walking Living Circle (Top: Real-World Trajectory Method; Bottom: Mobile Data Method)

APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION

There are a few details regarding the travel mode recognition process, as a supplement to 3.4.3.2:

First, if the travel times for two different travel modes from the navigation data are close (except when both modes are either green travel or non-green travel), the data will be classified as "other" and excluded. The definition of "close" is: the time difference between the two travel modes should be less than or equal to $\text{dur\_phone} * 0.125$. The use of the 0.125 factor provides higher accuracy in the **accuracy_fuzzy** method (as shown in Figure X), and it also results in a higher retention rate. Both **accuracy_fuzzy** and **retention rate** are determined by comparing the recognized results with travel data patterns from another source (Yu Zheng, 2010). This source of travel data contains 4610 records, which include OD (origin-destination) locations, travel times, and travel modes (walking, cycling, bus, and car). **Retention rate** refers to the proportion of data identified as one of the four travel modes relative to all identified data. **Accuracy** contains two dimensions: **accuracy_precise** and **accuracy_fuzzy**, referring to the percentage of correctly identified data among the recognized travel modes (as shown in Figure X).

Table C.1 Retention Rate and Fuzzy Accuracy as 'a' Changes. Source: Author's summary.

a	Retention rate	Fuzzy accuracy
0.1	0.83	0.84
0.11	0.85	0.85
0.12	0.85	0.86
0.125	0.85	0.86

(3 km, no bus service, off-peak hours)

APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION



Figure C.1 Retention and Accuracy. Source: Author's Plot

Additionally, if the time for the most likely travel mode calculated by Gaode Map (dur_mode) differs significantly from the actual time (dur_phone), the data will be classified as "other" and discarded. The criterion for "significant difference" is: $dur\_mode/dur\_phone > 99\%\_mode$ and $dur\_mode/dur\_phone < 1\%\_mode$. The $99\%\_mode$ and $1\%\_mode$ represent the 99th and 1st percentiles of the dur_mode/dur_phone values for the correct data for a specific travel mode, respectively (in the figure, Y represents correct, N represents incorrect).

For example, if the most likely travel mode is a car, and $dur\_car/dur\_phone \leq 1.98$ and ≥ 0.34 , the data will be retained. The value 1.98 represents the $99\%\_mode$ for car travel, and 0.34 represents the $1\%\_mode$ for car travel. The correctness of the data is determined by comparing the recognition results with 4610 travel data points.

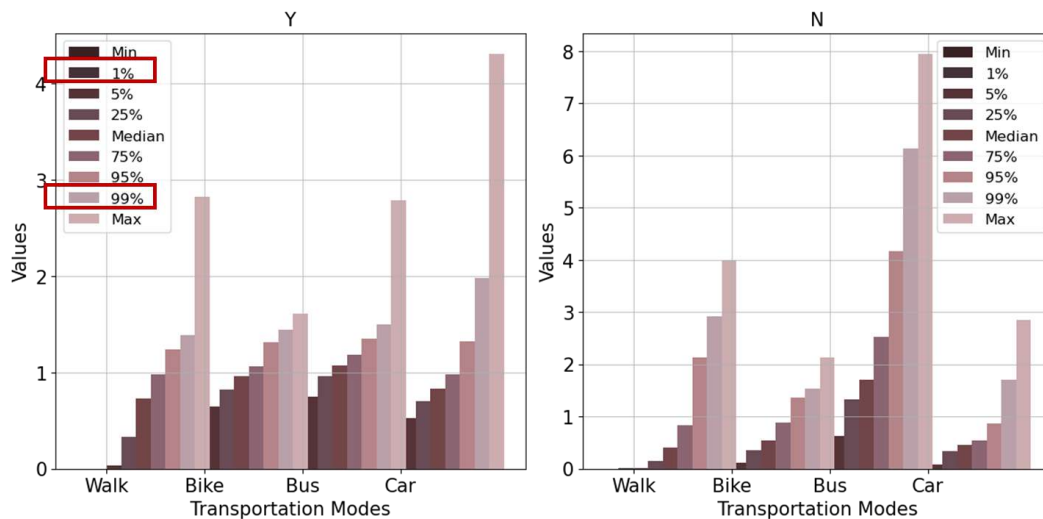


Figure C.2 Retention and Accuracy. Source: Author's Plot

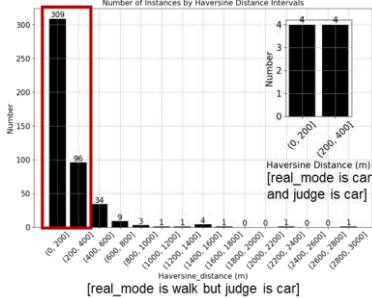
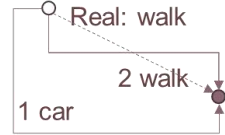
APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION

Thirdly, each judgment will be verified whether it belongs to three common misjudgments: walking to a car, taking a bus to a bicycle, or walking to a bus. If it does, and the judgment meets the changing conditions, it will be changed to another judgment result. The min mode represents the most likely mode of travel that is closest to the travel time of dur_phone, while the min_decond mode represents the second most likely mode of travel that is closest to the travel time of dur_phone (Table x, x).

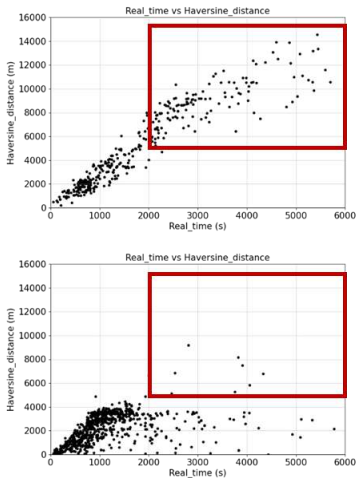
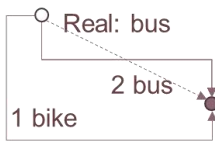
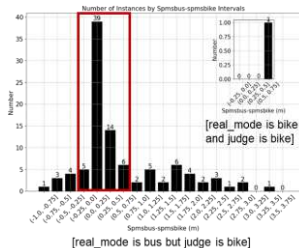
Table C.2 Data volume of three misjudgment types in the table. Source: Author's summary.

Actual mode	Misjudgment	Count	Percentage
Walking	Car	467	53.07%
Bus	Bicycle	380	49.74%
Walking	Bus	233	26.48%

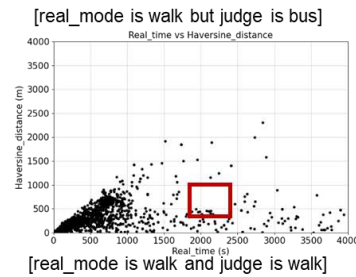
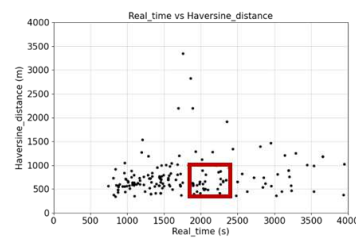
Table C.3 Misjudgments and corresponding changing conditions. Source: Author's summary.

1. Misjudgment and variation	If judge = Car Then judge = Walking		
1. Reasons for misjudgment	Actual walking time is short, but walking duration obtained from Amap is long. Meanwhile, car duration is short. This occurs more frequently in short trips. Compared with actual walking time, car duration aligns much closer than walking duration.		
1. Changing conditions	haversine_distance <= 400  Number of Instances by Haversine Distance Intervals Haversine Distance (m) [real_mode is car and judge is car] Haversine Distance (m) [real_mode is walk but judge is car]	distance_car > distance_walk Most data (460/468) show car travel distance obtained from Amap exceeds walking distance. For 400-meter distances, if car routes are longer than walking routes, people may prefer walking due to parking inconveniences. Time spent picking up/dropping off cars could already cover the destination arrival time.	min mode = car and min_second=walk 

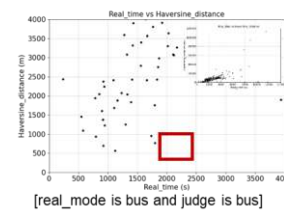
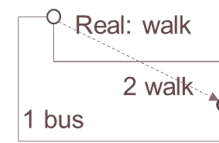
APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION

2. Misjudgment and Variation	If judgment = Bicycle Then judgment = Bus		
2. Reasons for Misjudgment	Actual bus travel time is shorter, but bus duration obtained from Amap is longer. Meanwhile, bicycle duration is shorter. This occurs more frequently in medium-distance trips. Compared with actual bus travel time, bicycle duration aligns closer to the actual bus travel time.		
2. Changing Conditions	haversine_distance >= 5000 and real_time >= 2000	spmsbus-spmsbike >= -0.25 and <= 0.75	Minimum mode = Bicycle and Minimum seconds = Bus
		For such long distances, if buses are faster (or slightly slower than cycling), people tend to choose buses. If bicycles are selected, it constitutes a misjudgment.	
			
3. Misjudgment and Variation	If judge = Bus Then judge = Walking		
3. Reasons for Misjudgment	Actual walking time is shorter, but walking duration obtained from Amap is longer. Meanwhile, bus duration is shorter. This occurs more frequently in medium-distance trips. Compared with actual walking time, bus duration aligns much closer than walking duration.		
3. Changing Conditions	haversine_distance >= 400 and <= 1000 and real_time >= 1800 and <= 2400		Minimum mode = Bus and min_second = Walking

APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION



By comparing the scatter distribution of misjudged walking as bus, correctly judged walking as walking, and correctly judged bus as bus, we can identify this interval, which not only "recovers" misjudged samples but also prevents correctly judged samples from being misjudged.



Fourthly, in order to avoid low retention rates, certain data identified as "other" is modified into four patterns when certain conditions are met. This is based on a common sense that residents usually choose the same mode of transportation from home to the same destination, especially to their workplace. Therefore, if a resident's data is identified as 'other' and most of their other data is processed in the same way, this data will be changed to the same way. There are some thresholds here. For work trips, residents identified as "no other" must have more than 3 trips and their start times must be at the same time (4:00-9:30 or 10:30-15:30), and the amount of data obtained by the resident through the same method must exceed 0.5. For daily travel, residents identified as "no other" must have more than 3 trips and the amount of data obtained through the same method must exceed 0.8. 'Other' contains two types: 'oth_clo' and 'oth_ques', indicating that the data was deleted because its time was close to the time of the other patterns in the first step, or its time was too different from the dur_phone in the second step. If a resident's data is identified as "oth_clo" and meets the above conditions, it will be changed to the same pattern. If a resident's data is identified as "oth_ques" and meets the above conditions, it is also necessary to test whether their speed is within the normal speed range of this mode in Tangshan City (car: 2.24-19.70; bus: 0.43-5.31; bicycle: 2.30-3.53; walking: 1.00-1.25 m/s). If so, the same mode will be changed (as shown in the figure).

APPENDIX C MOBILE DATA AND PROCESSING SPECIFICS FOR TRAVEL MODE RECOGNITION

A	B	G	H	M	N	O	P	Q	R	S	Y	AR	BA	BB
FID	time	time	tal2	no12	ptype2	tal3	no13	ptype3	stay_fre3	real_dis	judge	judgetw		
15966	2020-10-14T10:09:44.000	319	39.6546	118.1552	1	39.64175	118.1872	0	3	3085.388	oth_ques	oth_ques		
15967	2020-10-18T06:29:08.000	155	39.6546	118.1552	1	39.6724	118.1707	0	4	2379.243	oth_ques	oth_ques		
15968	2020-10-01T08:49:06.000	706	39.6546	118.1552	1	39.6724	118.1707	0	4	2379.243	car	car		
15973	2020/10/20 6:33	2353	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_clo	walk		
15974	2020/10/16 6:47	1559	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	walk	walk		
15975	2020/10/4 6:42	2074	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_clo	walk		
15976	2020/10/21 6:41	1700	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	walk	walk		
15977	2020/10/28 6:55	490	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	car	car		
15978	2020/10/31 7:17	2	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_ques	oth_ques		
15979	2020/10/12 7:15	80	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_ques	oth_ques		
15980	2020/10/4 17:45	198	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_ques	oth_ques		
15981	2020/10/15 6:52	922	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	bike	bike		
15982	2020/10/18 18:59	889	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	bike	bike		
15983	2020/10/19 6:37	1764	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	walk	walk		
15984	2020/10/22 6:41	2288	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_clo	walk		
15985	2020/10/14 7:00	947	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	bike	bike		
15986	2020/10/2 19:45	105	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_ques	oth_ques		
15987	2020/10/26 7:17	133	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	oth_ques	oth_ques		
15988	2020/10/23 6:41	1267	39.65422	118.1553	1	39.6502	118.1746	2	24	1714.379	walk	walk		
15989	2020-10-15T15:52:33.000	296	39.65406	118.1536	1	39.63206	118.1611	2	6	2529.078	car	car		
15990	2020-10-16T15:55:19.000	1174	39.65406	118.1536	1	39.63206	118.1611	2	6	2529.078	bike	bike		

Figure C.3 Some data in the chart were identified as 'other' and modified into four patterns (walking is the domain model of the resident). Source: illustrated by the author.

A	B	G	H	M	N	O	P	Q	R	S	Y	AR	BA	BB
FID	time	time	tal2	no12	ptype2	tal3	no13	ptype3	stay_fre3	real_dis	judge	judgetw		
507	2020-10-27T03:07:30.000	0	39.61594	118.1298	0	39.60947	118.1277	1	41	741.8775	oth_ques	oth_ques		
514	2020-10-27T13:42:51.000	467	39.61575	118.129	1	39.59022	118.136	0	2	2900.802	car	car		
515	2020-10-26T13:44:40.000	119	39.61575	118.129	1	39.59022	118.136	0	2	2900.802	oth_ques	oth_ques		
520	2020/10/15 8:13	88	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	oth_ques		
521	2020/10/23 8:10	822	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
522	2020/10/16 14:08	248	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
523	2020/10/22 14:13	449	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
524	2020/10/9 8:23	75	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	oth_ques		
525	2020/10/5 8:15	495	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
526	2020/10/30 14:12	666	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
527	2020/10/19 8:14	558	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
528	2020/10/18 14:08	199	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
529	2020/10/13 8:18	732	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
530	2020/10/3 8:29	199	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
531	2020/10/12 14:13	198	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
532	2020/10/4 14:14	199	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
533	2020/10/8 14:12	559	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
534	2020/10/25 7:45	2465	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	walk	walk		
535	2020/10/20 14:13	522	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	car	car		
536	2020/10/19 11	198	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	car		
537	2020/10/24 14:08	146	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	oth_ques	oth_ques		
538	2020/10/31 8:12	1021	39.61505	118.1288	1	39.62965	118.1553	2	31	2791.261	bike	bike		
542	2020-10-17T10:36:17.000	86	39.61561	118.1295	1	39.62596	118.1412	0	1	1526.188	oth_ques	oth_ques		
545	2020-10-04T10:02:22.000	185	39.61592	118.1296	1	39.62288	118.144	0	3	1452.716	oth_ques	oth_ques		

Figure C.4 Some of the data in the figure was identified as 'other' and modified into four patterns (with cars being the dominant model for the resident). Source: illustrated by the author

APPENDIX D THE SPECIFICS FOR 'CRITERIA FOR VARIABLE SELECTION: SCALE AS A REPRESENTATIVE SUPPLY FEATURE'

There are a few details regarding the reason why Scale was chosen as a representative supply feature, as a supplement to 6.1.4.1:

The study defines three types of flow clusters: **Nearest Flow Cluster**, **Most Frequent Non-Nearest Flow Cluster**, and **All Non-Nearest Flow Clusters** (including the most frequent non-nearest flow cluster), and uses this to evaluate the phenomenon of "near-near" behavior.

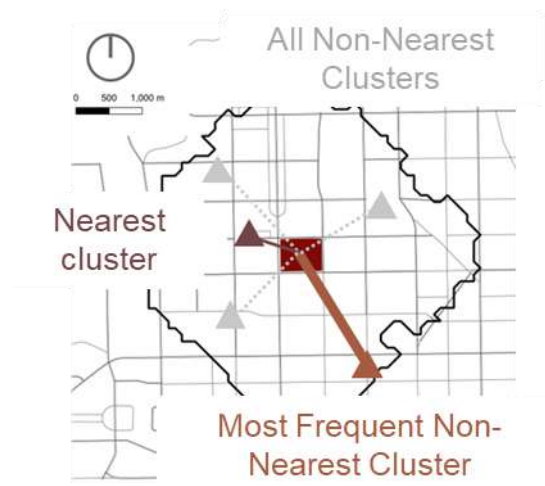


Figure D.1 Visualization of Nearest Flow Cluster, Most Frequent Non-Nearest Flow Cluster, and All Non-Nearest Flow Clusters

The degree of "near-near" behavior is composed of five dimensions:

- 1 Proportion of samples with "near-near" behavior
- 2 Distance between the nearest flow cluster (purple) and the most frequent non-nearest flow cluster (orange)
- 3 Distance between the nearest flow cluster and the weighted average distance of all non-nearest flow clusters
- 4 Comparison of travel counts between nearest and non-nearest flow clusters
- 5 Comparison of travel counts between the nearest flow cluster and all non-

APPENDIX D CRITERIA FOR VARIABLE SELECTION: SCALE AS A REPRESENTATIVE SUPPLY FEATURE

nearest flow clusters

Table D.1 Evaluation Dimensions and Corresponding Samples

Evaluation Metrics	All Samples	Residential quarter	Single Samples	Residential quarter	quarter
1 Proportion of Flow Clusters with More Than One Sample	Yes		No		
2 Maximum Distance Difference Between Nearest and Farthest	Yes		Yes		
3 All Nearest Distance Differences	Yes		Yes		
4 Nearest Maximum Frequency Differences	Yes		Yes		
5 All Nearest Frequency Differences	Yes		Yes		

Figure: Evaluation of "Near-Near" Behavior in Shopping Facility Trips for Various Residential Samples

The shopping facility trips show a strong "preference for distant destinations" feature.

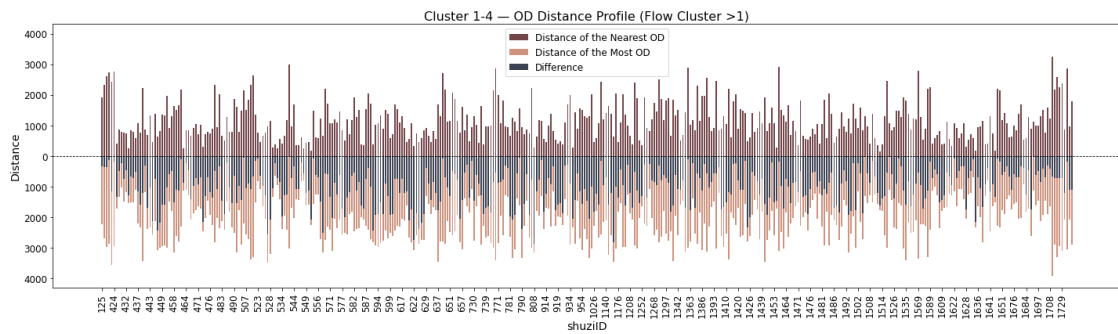


Figure D.2 OD Distance of supermarket

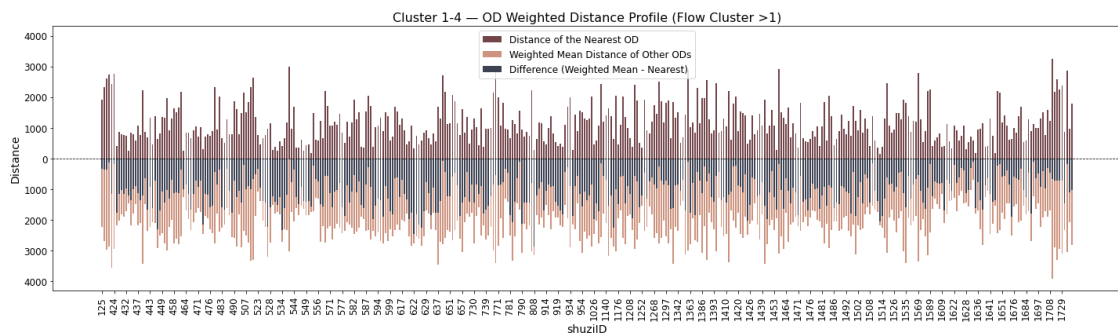


Figure D.3 OD weighted distance of supermarket of supermarket

APPENDIX D CRITERIA FOR VARIABLE SELECTION: SCALE AS A REPRESENTATIVE SUPPLY FEATURE

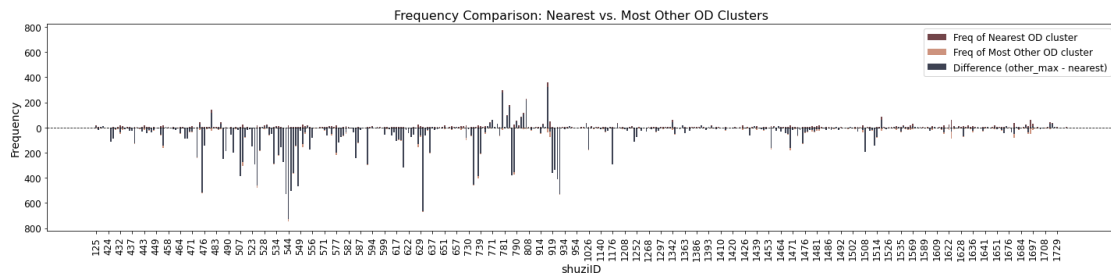


Figure D.4 Frequency comparison of the nearest and the most OD clusters of supermarket

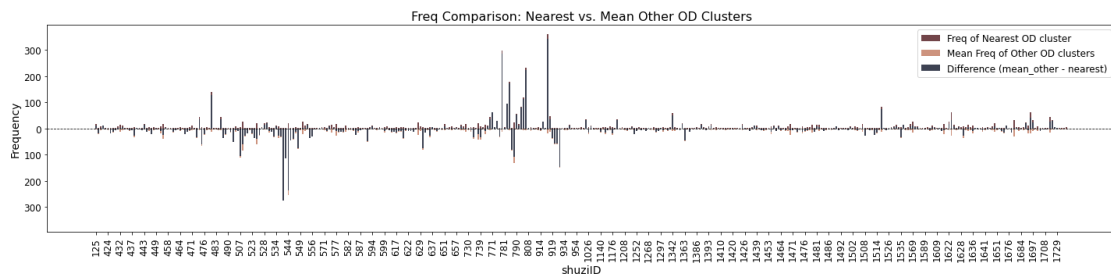


Figure D.5 Frequency comparison of the nearest and mean of other OD clusters of supermarket

Evaluation of sample supermarkets in various residential quarters based on proximity (nearest maximum distance difference, nearest total distance difference, nearest maximum frequency difference, nearest total frequency difference)

Market trips show relatively better proximity performance with lower attraction to distant destinations.

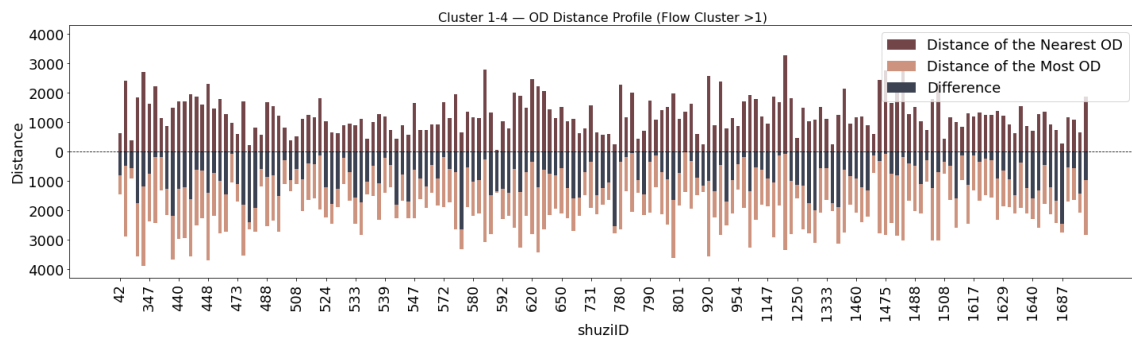


Figure D.6 OD Distance of vegetable market

APPENDIX D CRITERIA FOR VARIABLE SELECTION: SCALE AS A REPRESENTATIVE SUPPLY FEATURE

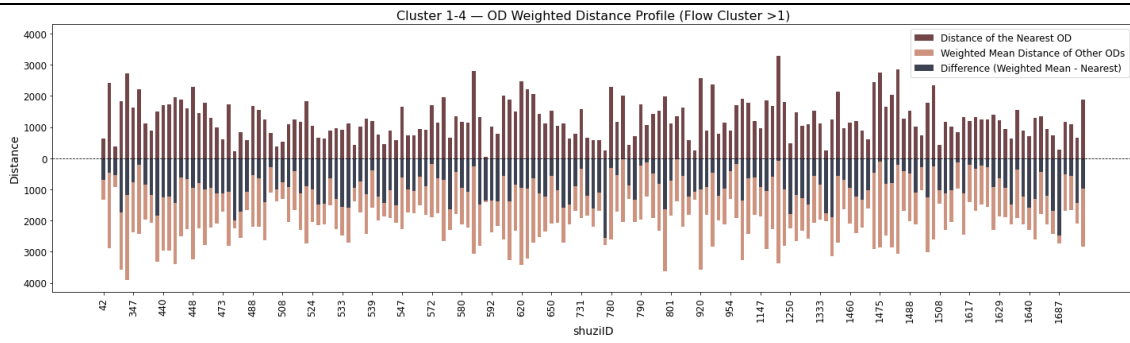


Figure D.7 OD weighted distance of vegetable market

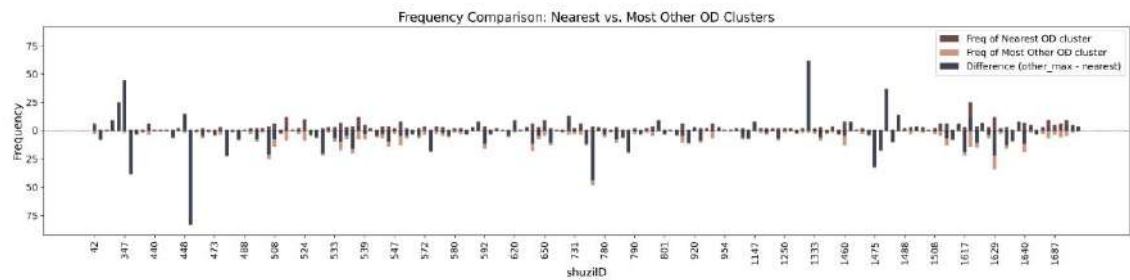


Figure D.8 Frequency comparison of the nearest and the most OD clusters of vegetable market

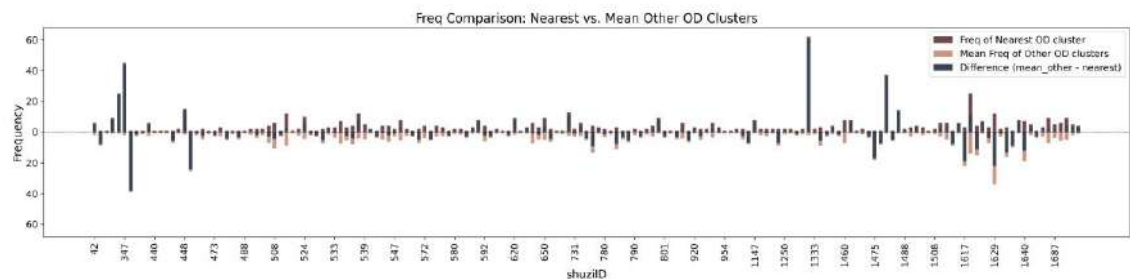


Figure D.9 Frequency comparison of the nearest and mean of other OD clusters of vegetable market

Evaluation of Sample Vegetable Markets in Various Residential quarters, Focusing on Distances (Differences in Nearest and Most Distances, Differences in Nearest and All Distances, Differences in Nearest and Most Frequent Times, Differences in Nearest and All Frequent Times)

Based on the OD flow cluster data and Dianping data in section 7.2.2. The OD flow cluster consists of 757 residential quarter vegetable market flow clusters and 2927 residential quarter supermarket flow clusters within the 15 minute cycling living circle; Dianping collected 3025 Dianping reviews from 35 supermarkets and 724 Dianping reviews from 46 markets in May 2025.

The method is to take the residential quarter living circle as a sample, compare the characteristics of the nearest flow cluster and non nearest flow cluster endpoint supermarket within the 15 minute living circle (12, one by one), and summarize the differences in these living circle characteristics. If the non nearest flow cluster characteristics are better than the nearest flow cluster, it proves that this feature is the reason for seeking distance instead of proximity. The formula is as follows:

A certain feature difference = sum of non nearest most flow cluster supermarket features $\times$ non nearest most flow cluster travel times - sum of nearest flow cluster supermarket features $\times$ nearest flow cluster travel times

$$\Delta Q = \sum_{i=1}^n (Q_{i\_most} \times Fre_{i\_most} - Q_{i\_nearest} \times Fre_{i\_nearest}) \quad \text{Equation D.1}$$

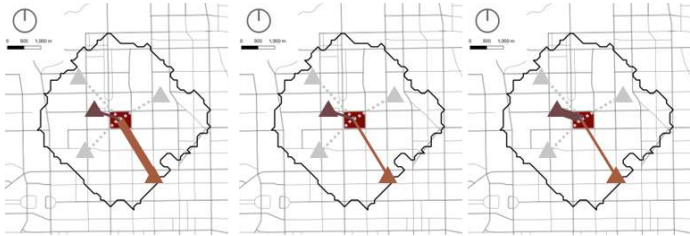
In the formula, ΔQ represents the contribution of a particular feature to the "choose further over closer" phenomenon. Here, i refers to residential samples, and n is the total number of residential samples. For each sample i , the feature quality of the most distant non-nearest flow-cluster supermarket Q_{i_most} and the nearest flow-cluster supermarket $Q_{i\_nearest}$ are determined based on sentiment analysis from public review data, where the values can be 1, 0, or -1. The travel frequency refers to the number of trips made to that flow-cluster supermarket, serving as the weight of quality, calculated from the total trips made between October 1st and 30th, 2020. Fre_{i_most} represents the travel frequency of the non-nearest most frequent flow-cluster, and $Fre_{i\_nearest}$ represents the travel frequency of the nearest flow-cluster.

Study Sample: The study sample consists of residential living circles with at least two flow-clusters, excluding those where the nearest flow-cluster has more trips than the non-nearest most frequent flow-cluster. The sample includes 315 supermarkets and 116 vegetable markets. In these samples, it is assumed that the long-distance trips are due to the significantly stronger features of the non-nearest most frequent flow-cluster supermarket (or vegetable market) compared to the nearest flow-cluster, which drives residents to choose more distant destinations. For example, when the nearest flow-cluster of a residential quarter has only one trip, while the non-nearest most frequent flow-cluster has 10 trips, it indicates that the distant facility has significant advantages in terms of feature quality, which leads to the occurrence of the "choose further over closer"

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phenomenon.

Table D.2 sample setting

	sup erm ark et	Veg etab le mar ket	Most>Nea rest	Most=Nearest	Most<Nearest
Number of residenti al quarters	315	116	√	√	×
diagram	— —	— —			

The 12 characteristics include: Year of Establishment; Per capita consumption: Per Capita Spending; Review Rankings: Customer Review Rankings; Product Quality: Product Quality; Environment: Ambience; Service: Service; Space Design: Spatial Design; Convenient transportation: Accessibility; Extended Functions; Scale Level: Scale Level; Complete range: Variety of Offerings; Auxiliary Facilities: Auxiliary Facilities. The 12 characteristic values of various supermarkets or markets are evaluated as 1, 0, -1, representing high quality, medium quality, and poor quality, respectively. The characteristic quality of supermarkets and vegetable markets is determined through the collaboration of manual instructions and big language models. The evaluation is communicated to the big language model (such as code) through instructions, and the model automatically scores the vegetable market. After quantitative comparison, the evaluation is accurate. Taking the feature "environment" as an example, when the word "clean environment" appears in the comment, the big language model determines that the market environment score for that dish is 1 point (as shown in the table).

The key code is as follows:

content = f''''

Please browse the following comments on Dianping to find the key sentence for the

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reason why the reviewer came to the mall, and analyze whether the emotional color is positive, negative, or neutral. Mark positive as 1, negative as -1, and neutral or no related comments as 0.

The differences in the vegetable market can be considered from these dimensions: construction year, per capita consumption, review rankings, operating hours, product quality, environment, service, spatial design, convenient transportation, extended functions, scale level, complete variety, and auxiliary facilities.

The term 'extended function' refers to leisure or social functions beyond shopping.

Finally, please output a JSON dictionary based on the analysis results, where the dictionary values are a list. The first element of the list is the emotional color annotation, and the second element is the "key sentence" used to determine the emotional color. The example is as follows:

```
{
  'Built year': [1, key sentence]
  'Per capita consumption': [0, key sentence],
  'Review ranking': [0, 'No relevant information']
}
```

The data from Dianping is as follows:

```
{comments}
""""
```

Table D.3 Vegetable market Quality Scores Evaluated Based on Large Language Model

VI D	Dianping Names of Tangshan Vegetable markets	Environme nt	Environment_Original Text
13	Wuhai Market	1	Market environment clean, produce fresh, meat fresh, merchandise complete, prices reasonable, hygienic and tidy, everything available. Overall quite good, inside has everything quite complete, hygiene maintained quite well
14	Wenbei Xilou Standardized Vegetable market	-1	But environmental hygiene poor, roads also lacking management
26	Majiatun Agricultural Market	0	Market environment average, just that agricultural market type, generally morning shopping has more varieties, more vendors. Winter afternoons relatively quiet

While verifying the effectiveness of scale as a facility feature, the model simultaneously fits the residential quarter sensitivity coefficients - scale preference coefficient (γ) and distance sensitivity coefficient (λ). When verifying the effectiveness of scale, this article only used travel data within the 15 minute living circle. When constructing the sensitivity coefficient, this article used travel data at two levels: within the 15 minute living circle and throughout the city.

The details of the global fitting model method are as follows. After calculating SSE, set the distance attenuation coefficient λ and scale validity coefficient γ parameters and step size for the model, and generate multiple sets of parameter combinations by crossing the two parameters. Train the Huff model on all residential quarter samples for each parameter combination, and calculate the total sum of squared residuals SSE between the predicted and actual travel probabilities for all residential quarters globally. This process is performed on all residential quarter samples; Choose the parameter combination that minimizes SSE as the global optimal solution for this type.

$$(\lambda^*, \gamma^*) = \arg \min_{\lambda, \gamma} \{SSE(\lambda, \gamma)\} \quad \text{Equation D.2}$$

Visualization: Use the SSE result as the z-axis of the (λ , γ) two-dimensional parameters to draw a three-dimensional surface graph, which is used to observe the observation trend of error values changing with parameters during the model adjustment process.

The R2 value is an indicator that measures the goodness of fit of a model. In this study, it is used to determine the degree of fit between the predicted travel probability P_{ij} of the Hough model and the actual travel probability P_{ij} , in order to test the effectiveness of scale as a dimension of supply scale.

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \quad \text{Equation D.3}$$

$$SS_{res} = \sum_{i,j} (P_{ij} - \hat{P}_{ij})^2 \quad \text{Equation D.4}$$

$$SS_{tot} = \sum_{i,j} (P_{ij} - \bar{P})^2 \quad \text{Equation D.5}$$

Among them, SSres is the sum of squared residuals of the model, representing the

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error between the predicted and actual values, that is, the sum of squared errors between the predicted and actual values of OD flow clusters from each residential quarter to the supermarket; SS_{tot} is the total sum of squares, representing the degree of variation of actual data relative to its average, and is the average of the actual travel probabilities of all residential quarters to supermarket OD flow clusters.

The details of the residential quarter fitting method are as follows. After global modeling, independent parameter fitting is performed on each residential quarter to estimate individual level sensitivity differences. By modeling the travel data of residents in each residential quarter separately, the optimal distance attenuation coefficient (λ) and scale preference coefficient (γ) are separately fitted as attitude dimension independent variables in the later study of the relationship between facility layout and long-distance travel. Similar to global fitting, this study still uses Sum of Squared Errors (SSE) for parameter optimization. The specific steps are as follows:

Use the exponential function and SSE from the previous section as the prediction formula and residual sum of squares formula. Global modeling sums the squared differences between the predicted probabilities and actual probabilities of all flow clusters, while independent modeling of each residential quarter only sums the squared differences between the predicted probabilities and actual probabilities of all flow clusters in a specific residential quarter.

Traverse multiple combinations of λ and γ through grid search, select the parameter combination that minimizes SSE as the optimal parameter for the residential quarter, and perform this process independently in each residential quarter. The value range of λ is 0.1 to 9.9, with a step size of approximately 0.2; The value range of γ is 0.1 to 1.9, with a step size of approximately 0.0367. This parameter combination is traversed through grid search, generating a total of 2500 sets of (λ, γ) parameter pairs.

Table D.4 Network Settings for Two Sensitivity Coefficient Parameters of Exponential Function

Parameter Type	Parameter	Value Range	Step Size	Segment Count	Total Parameter Combinations
Exponential Function Huff Model	λ (lambda)	0.1 - 9.9	Approximately 0.2	50	2500
	γ (gamma)	0.1 - 1.9	Approximately 0.0367	50	

This article excluded samples from residential quarters where the actual number of visits to supermarkets is less than or equal to 2, and only analyzed samples from other residential quarters using the three steps mentioned above. The reason is that when there are too few travel records in the supermarkets of residential quarters, the distance attenuation coefficient (λ) and scale preference coefficient (γ) in the Hough model will face the problem of fitting uncertainty. Especially in the case of only two supermarkets, the model can only provide a ratio constraint, resulting in underdetermined fitting equations and inability to uniquely determine parameter solutions. In addition, insufficient observation points may lead to overfitting of individual samples in the model, resulting in parameter polarization (such as too small λ or too large γ), which reduces the explanatory power and generalizability of the results. Therefore, in order to obtain parameter results with statistical significance and behavioral explanatory power, it is necessary to limit the sample to include at least three or more supermarket travel records.

In 1964, when Haff proposed the model, in order to estimate λ , a method was used to maximize the correlation coefficient (r) between simulated predicted probabilities and actual probabilities. Haff hoped to make the predicted travel allocation of the model more "linearly correlated" with real observations. In contrast, the reason and advantages of the SSE method adopted in this study are: 1 SSE is a more modern and widely recognized estimation method (Corning, Niu Xinyi, 2024); 2. The maximum value of r is usually highly consistent with the minimum value of SSE; 3. It has extensibility and can be used for statistical inference or confidence interval estimation.

APPENDIX E CALCULATION AND OTHERS

1 Weight calculation

The data is sourced from surveys conducted among residents in Turin, Italy, Tangshan, and Beijing, China (the process is illustrated in the figure). The weights for each type of facility are as table E.1 shows.

Table E.1 The weight of each type of facility. Source: summarized by the author.

	category	weight
A shopping	A.1 suppermarket	0.048
	A.2 vegetable market_open air market	0.042
	A.3 community commercial outlets	0.043
	A.4 catering	0.042
	A.5 express_postal outlets	0.035
B caring	B.1 health service center	0.092
	B.2 gym_fitness center	0.072
	B.3 pharmacy	0.024
C learning	C.1 middle	0.096
	C.2 primary	0.179
	D.3 kindergarten	0.113
D enjoying	D.1 community service center	0.088
	D.2 park_square_attractions	0.083
	D.3 cultural venue	0.043

The weight calculation is Analytic Hierarchy Process through website: <https://www.expertchoice.com/>. The subjects (more than 10) are required to compare the importance between types of facilities (figure), then the weight assessments are calculated. The weights have been modified slightly because the categories were different when the questionnaires were conducted, but the ratios of weights of type of facilities are kept.

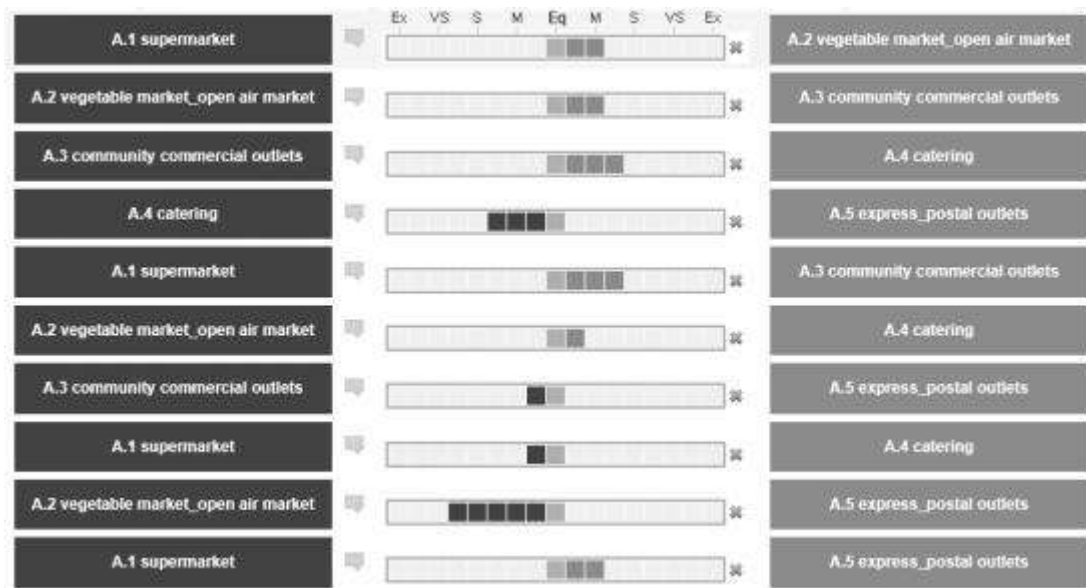


Figure E.1 The importance of two types of facilities was compared in the questionnaire. Source: Drawn by author.

2 Elbow method

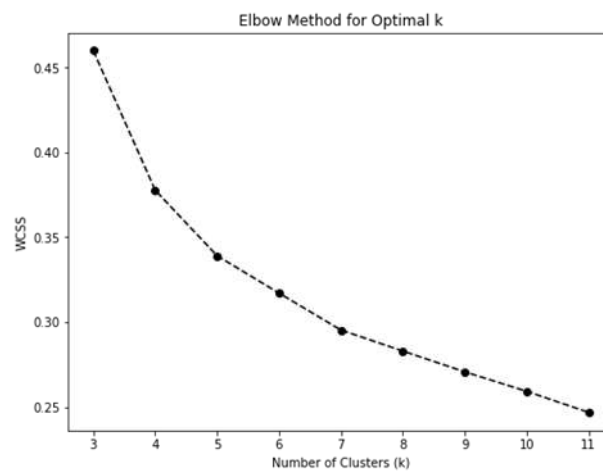


Figure E.2 WCSS for Different Cluster Counts

3 The basis of 5 categories and 16 types of facilities

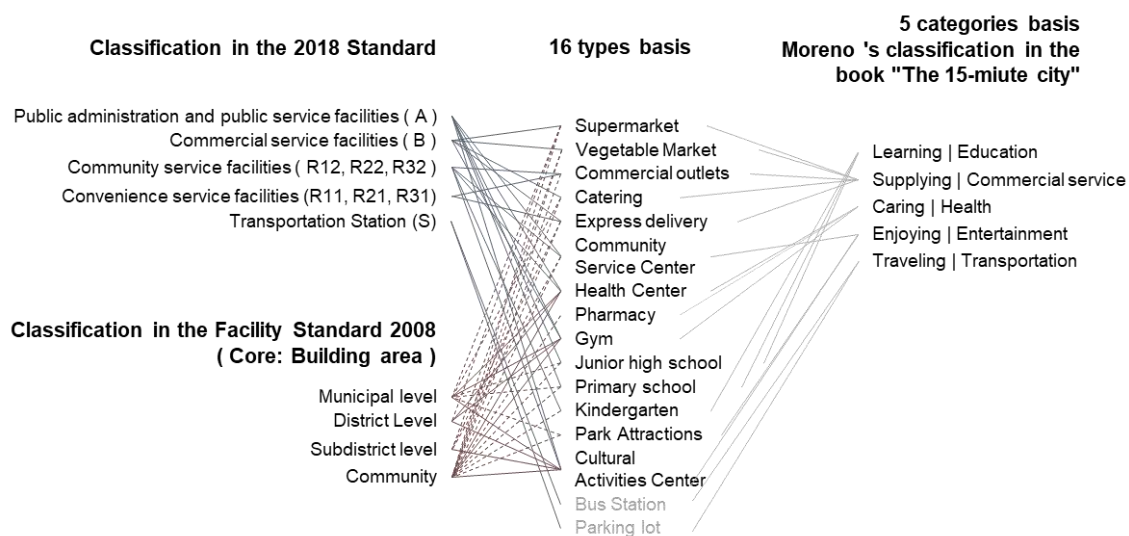


Figure E.3 The basis of classification of facilities