Multi-dimensional Evaluation of Beijing Tongzhou Sub-Center and Downtown Area Commuter Rail Optimization Project (2023–2025): Case Study of Metro Line 6 Frequency & Hub

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Abstract

This study evaluates the core policy "The Tongzhou District Comprehensive Traffic Management Action Plan (2025)" in Beijing Tongzhou Sub-Center and Downtown Area Commuter Rail Optimization Project (2023–2025) from the three dimensions of neoclassical efficiency, sustainable transportation accessibility and spatial fairness. The research adopts a mixed research method to build a deep analysis framework. First, in the quantitative analysis part, models such as generalized travel cost, potential accessibility and Gini coefficient are used to make a preliminary analysis of the policy. Secondly, in the qualitative analysis part, the policy is evaluated in depth in combination with empirical results. The empirical results initially show that although the policy has successfully reduced the overall cost of commuting and significantly improved sustainability indicators such as employment accessibility, its benefits are unevenly distributed spatially and highly concentrated in the core hub of Tongzhou, resulting in a further widening of the gap with non-core regions. The qualitative analysis combined with empirical results further points out that efficiency-oriented optimization may aggravate the internal imbalance while improving system efficiency. To this end, it is proposed to institutionalize fairness indicators and implement a targeted compensation mechanism to balance efficiency and spatial justice and ensure that the dividends of transportation development are shared more fairly.

Keywords

Commuter Rail Optimization, transport equity, spatial accessibility, generalized travel cost, polycentric development.

1. Introduction

1.1. Research Background

In recent years, Beijing has moved non-capital functional administrative institutions to Tongzhou, the sub-center, and built a multi-center urban network governance structure [13], which provides an institutional basis for the formulation of regional transportation policies. This transformation has made the efficient commuting between Tongzhou and the central urban area of Beijing more and more prominent, and traffic connectivity has become a key point for regional coordination. In Beijing, the space misalignment of unbalanced work and living has aggravated the pressure of commuting. Research shows that the changes in the employment-housing structure in Beijing significantly affect the way of travel [10]. The empirical analysis of large-scale travel data further reveals that the distance between urban commuting in China and the distance in the city center has an inverted U-shaped relationship, indicating that there are spatial limitations in the central attraction [5].

As the main railway corridor connecting Tongzhou and the central city, Beijing Metro Line 6 bears a large number of passengers between the two places, but it also faces the problem of increasing operational pressure. The Tongzhou District Comprehensive Traffic Management

Action Plan (2025) puts forward 72 measures, focusing on promoting the capacity increase, hub optimization and accessibility improvement of Line 6, aiming to build a "convenient, green, intelligent, safe and efficient" operating environment. The policy provides a clear framework for evaluating the upgrade of Line 6, while emphasizing the strategic focus of improving infrastructure efficiency and optimizing the spatial structure of the sub-central region.

1.2. Research Significance

This study builds a tripartite analysis framework that combines efficiency (neoclassical economics), structural sustainability (sustainable urbanization) and equity (critical paradigm) to assess how interventions such as increasing the frequency of departures and optimizing hubs affect commuting efficiency, spatial structure and social equity.

1.3. Research Questions and Argument

This study explores the following issues: To what extent have the increase of 6 lines and the optimization of hubs improved efficiency and sustainability? Will these measures exacerbate spatial inequality in the sub-central region?

The core argument of this study is that although these optimization measures can bring positive efficiency and structural results, their "hub-first" strategy may exacerbate the problem of spatial equity.

1.4. Paper Structure

The structure of this article is as follows: the second part reviews the literature and builds a theoretical framework; the third part summarizes the research design and data; the fourth part conducts quantitative analysis; the fifth part conducts qualitative policy analysis; the sixth part summarizes the research results and discusses the significance of governance.

2. Literature Review and Theoretical Framework

Current research on commuting railway optimization (especially increasing departure frequency and improving hub connectivity) has revealed significant gaps in three theoretical dimensions: neoclassical efficiency, sustainability and spatial equity.

From the perspective of efficiency (neoclassical economics), the classic model of Small, Verhoef and Robin (2007) shows that the broad cost of travelers (including time and money expenditure) will affect the choice of travel mode and overall social welfare [21]. Policy means such as fare adjustment and departure frequency can improve system efficiency. They emphasize system integration: even if the departure frequency is increased, the lack of coordinated scheduling may weaken economies of scale. However, in urban areas such as Jingtong, which have many sub-centers and complex railway networks, there is still a lack of comprehensive cost models that incorporate the transfer hub effect.

From the perspective of sustainability, the "Avoid-Shift-Improve" (ASI) framework proposed by Banister (2008) advocates: first, "avoid" travel needs; second, "transfer" to more environmentally friendly travel Method; Finally, "improve" system quality or energy efficiency [4]. Although urban studies have explored the transformation of travel modes (for example, the balance between employment and housing), few studies have examined how the increase in subway services and the integration of multimodal transport hubs can drive long-term environmental benefits, such as spatial restructuring, under the element of "improvement".

From the perspective of critical spatial justice, Martens (2016) proposed a three-dimensional justice framework in his book Transport Justice: distributional justice, procedural justice and relational justice. Procedural justice emphasizes public participation and transparency in decision-making; relationship justice focuses on how accessibility and power structures exacerbate social inequality [15]. The new travel paradigm proposed by Sheller and Urry (2006) further points out that travel is inherently political and influenced by power relations [20]. Although these theories have been developed in Western transportation equity research, China's empirical research - especially in subway optimization and sub-center development - rarely examines the power dynamics of public participation (procedural fairness) or spatial accessibility (relationship equity).

Based on these perspectives, this study builds a comprehensive analytical framework that integrates efficiency (cost-frequency model), sustainability (ASI framework) and critical spatial equity (distribution/process/relationship dimension). Through this three-dimensional perspective, we use a combination of quantitative and qualitative methods to evaluate how the frequency of commuter railway services and hub optimization affect travel costs, network performance, urban structural stability and social equity.

3. Methodology and Data

3.1. Research Design

This study adopts a mixed research method, combined with quantitative analysis and policy text analysis, and comprehensively evaluates the Action Plan for Comprehensive Traffic Management in Tongzhou District 2025 from the three dimensions of efficiency, sustainability and fairness [2]. The research focuses on Metro Line 6 and analyzes its policy effects on improving the departure frequency, enhancing the connectivity of hubs and promoting spatial restructuring. In terms of spatial division, the area within a radius of 1500 meters of the site is defined as the hub core area, and the outside is defined as the non-core area, and the central urban area site is selected as a comparison to compare the accessibility and service differences of different areas.

3.2. Data Sources

This study adopts multi-source data: travel time data of Gaode Map API; population employment data of Beijing Municipal Bureau of Statistics; land use and POI data of OpenStreetMap (covering 2023 and 2025, used to measure travel cost, accessibility and spatial distribution); the Action Plan for Comprehensive Traffic Management in Tongzhou District in 2025 as the basis for policy analysis.

3.3. Analytical Models

3.3.1. Neoclassical Efficiency Model: Generalized Travel Cost

This article calculates the comprehensive travel cost, which is combined with travel time and monetary expenditure. The travel time is monetized according to the average wage level in Beijing to estimate the opportunity cost. This method derived from transportation economics reflects the non-monetary (time) and monetary burden [6], so that it can assess how policy changes affect the burden of commuters:

$$C = Tt \cdot VOT + F \tag{1}$$

Where: C: Generalized travel cost (unit: CNY); Tt: Total travel time (unit: hours, using the average travel time throughout the day); VOT: Value of time (valued at 34.4 CNY/hour, based on the average level in Beijing); F: Metro fare (Beijing's metro system uses a distance-based fare structure, typically ranging from 5 to 6 CNY)

3.3.2. Sustainable Transport Model: Accessibility Assessment

The accessibility model based on gravity can capture sustainability results. The model calculates the potential accessibility index before and after the implementation of the policy to measure how the improvement of traffic frequency and hub connectivity changes people's access to jobs and services [18].

This paper adopts the power law impedance function, and the parameter β changes with the regional type (hub core area/non-core area/central urban area), reflecting the spatial differences in urban structure and the sensitivity of travelers to time costs. This explains distance decay: power-rhythm impedance has been proven to be suitable for simulating long-distance or non-scale spatial interactions [16], while classical studies point out that attenuation parameters change with the centrism of the starting point [8]. Recent empirical studies support region-specific beta values [22].

Distance decay parameters are set according to the regional type: core hub area β≈2, non-core area β≈1, central urban area β≈3. Referring to the research of Švěda et al. (2023), they found that the distance decay in the core area of dense cities is more significant than that in the suburbs[23]:

$$A_j = \sum_j \frac{O_j}{f(T_{ij})} \tag{2}$$

$$f(T_{ij}) = T_{ij}^{\beta} \tag{3}$$

Where: A_j : Accessibility index for station j; O_j : Total opportunities in region j (including employment opportunities, public service facilities, etc.); $f(T_{ij})$: Impedance function (reflecting the travel time friction between station i and region j)

3.3.3. Critical Equity Model: Accessibility Gini Coefficient

In the equity analysis, the Gini coefficient quantifies the accessibility inequality between different spatial regions (for example, the hub core region and the non-core region). The model compares the degree of inequality before and after the implementation of the policy, and derives the Lorentz curve to evaluate the cumulative reach distribution. Its application in traffic equity has been verified in previous studies [11]:

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |A_i - A_j|}{2n^2 \bar{A}} \tag{4}$$

Where: G: Gini coefficient for accessibility (ranging from 0 to 1, where values closer to 1 indicate greater inequality); A_i, A_j: Accessibility indices for region i and region j, respectively; $\bar{A}$: Mean accessibility index across all regions; n: Total number of regions in the study, the number of regions is 33, calculated based on the division of the central urban area, core hub area, and ordinary districts.

4. Empirical Analysis

This section introduces the main empirical research results of three analytical models (neoclassical efficiency, accessibility of sustainability orientation and critical equity), as well as supplementary tests to verify the main results.

4.1. Efficiency Analysis: A Neoclassical Perspective

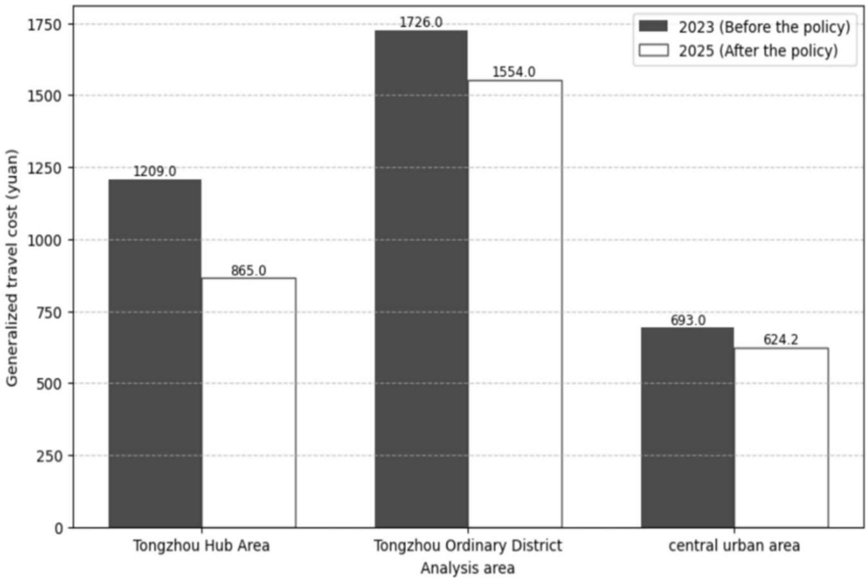

Figure 1. Neoclassical Perspective: Comparison of Generalized Costs Before and After Policy Implementation

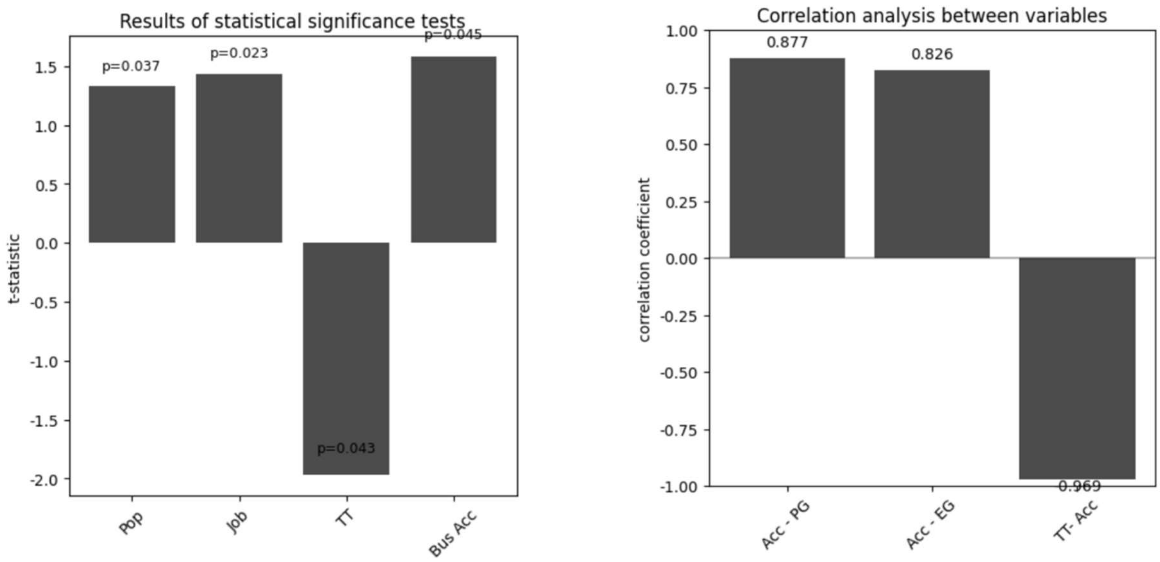

Figure 2. Statistical significance test and accessibility correlation analysis test

The calculation results of the efficiency model show that (comparing 2023 and 2025), in terms of the broad travel cost of time cost and subway fare, the cost of commuters in the core area of Tongzhou hub and non-core area decreased significantly, among which the core area decreased the largest (Figure 1: from about 1,209 yuan to about 865 yuan), and the center The cost of urban areas has not changed much. Considering that the basic fare and the city's wage level remained stable during this period, the neoclassical efficiency framework initially determined that the cost decline was attributed to the saving of travel time brought about by the policy, mainly due to the increase in train schedules and the optimization of transfers.

Further tests show that:

Figure 4 shows that the elasticity of the improvement of travel time on accessibility is estimated to be 3.137, that is, for every 1% reduction in time, the accessibility increases by about 3.137%, which is consistent with the classic theory of transportation economy [9], showing that public transportation users are extremely sensitive to time costs.

A paired-sample t-test was conducted to compare population, employment opportunities, accessibility and the generalized travel costs before (2023) and after (2025) the policy implementation. The result shows a statistically significant decrease in costs ($t = -1.970$, $p = 0.043$, Figure 2), indicating that observed decrease is not random. This confirms that the policy has a significant impact on reducing the overall cost of commuting. Given that the ticket price remains stable, the cost reduction is mainly due to the saving of travel time, which is consistent with the modeling results of the generalized cost function.

4.2. Accessibility Analysis: A Sustainability Perspective

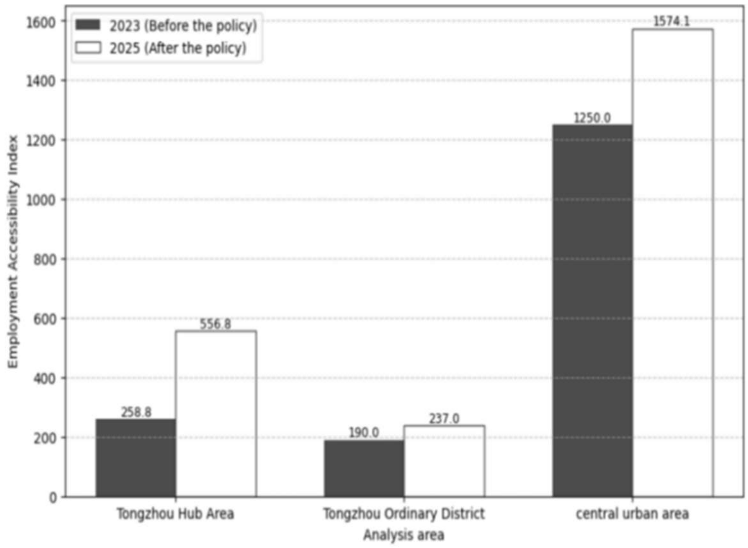

Figure 3. Sustainable Perspective: Comparison of Employment Accessibility Before and After Policy Implementation

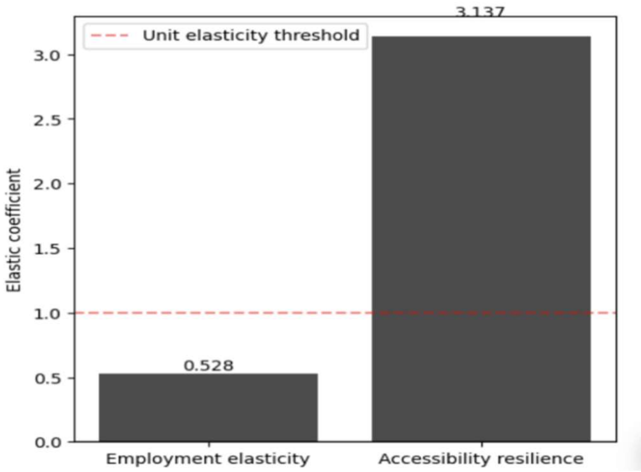

Figure 4. Analysis of travel time improvements on employment and accessibility elasticity

In order to assess the impact of the policy on accessibility, Figure 3 shows the potential accessibility index before and after the implementation of the policy is measured based on the employment center of gravity model. The analysis of hub core areas, non-core areas and central urban areas shows that after the implementation of the policy, the accessibility of all regions has improved significantly, and the employment accessibility of Tongzhou and central urban areas has improved significantly.

Correlation analysis further reveals:

Figure 2 shows that the correlation between accessibility improvement and employment growth is 0.826, which is a strong correlation; The correlation between accessibility improvement and population growth reaches 0.877, indicating that the region with large accessibility improvement is closely related to economic and residential expansion.

The model shows that the policy has promoted sustainable transformation, given rise to new micro-activity centers, and may promote the rebalancing of spatial structures.

4.3. Spatial Equity Analysis: A Critical Perspective

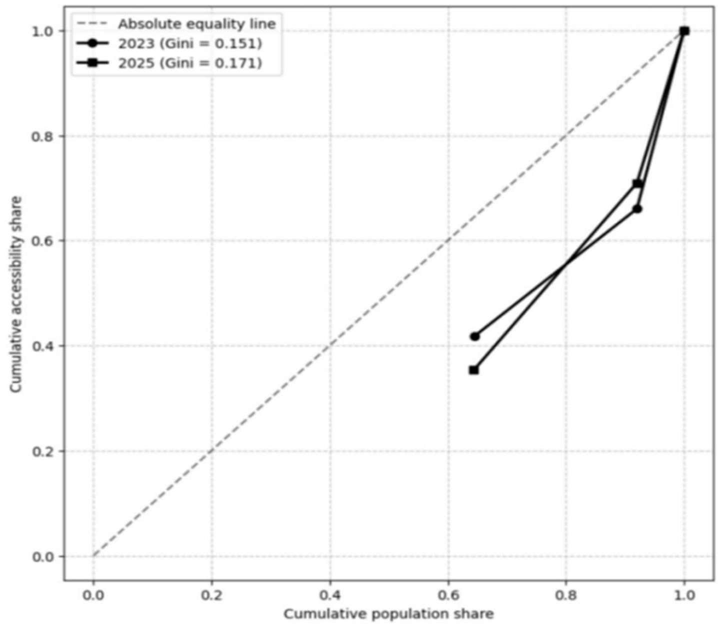

Figure 5. Critical Perspective: Lorenz Curve of job Accessibility

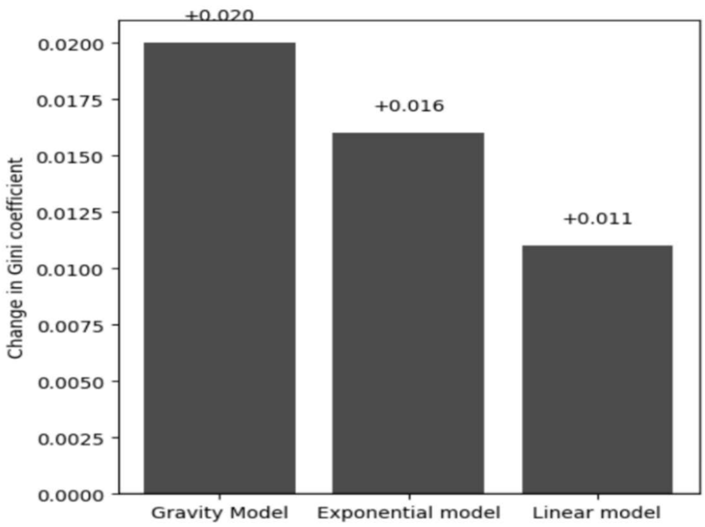

Figure 6. Robustness test: changes in the Gini coefficient

Spatial fairness is measured by the accessibility Gini coefficient, which rose from 0.151 in 2023 to 0.171 in 2025(Figure 5), showing a decline in fairness, mainly due to the concentration of policy resources in the hub core area, and the travel cost of the "last kilometer" of non-core areas is still high.

Figure 6 shows that inequality has increased under different models (the Gini coefficient increased by 0.0156 on average).

Figure 4 shows that response of employment to the improvement of travel time is low (0.528), suggesting the need to support local policies to narrow the space gap.

5. Discussion and Qualitative Analysis

5.1. Integrated Discussion

According to the results of empirical research, the policy presents a complex and contradictory situation. From the perspective of efficiency, the overall success of the policy: the improvement of service frequency and the optimization of hubs have significantly reduced the travel cost in a broad sense. However, this efficiency improvement is spatially uneven, raising concerns about sustainability. Model analysis shows that structural benefits such as transportation improvement and job-living balance optimization are highly concentrated in the core area of the hub, and the benefits of the surrounding areas are limited. From the critical perspective of spatial fairness, the concentration of resources leads to the strengthening of advantages and the lack of improvement of marginal areas. The increase in the Gini coefficient also confirms that the overall efficiency of the system has improved, while the spatial fairness has deteriorated [19].

Table 1 outlines the 72 measures of The 2025 Tongzhou District Comprehensive Transportation Management Action Plan. By classifying the measures within the policy according to the three dimensions of efficiency, sustainability and fairness, it is convenient for a deeper qualitative analysis of the policy in this section in combination with empirical results.

Table 1. Policy type overview of the 2025 Tongzhou District Comprehensive Transportation Management Action Plan

Type	Measure number	Overview of type measures
Efficiency	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 40, 48, 49, 50, 61, 63, 65, 66, 71	Improve the system capacity and running speed.This covers measures such as hub integration, checkpoint optimization, highway and railway construction, "cut-off road" repair, management mechanism research, congestion relief, intelligent transportation system, logistics facility planning and traffic signal improvement.
Sustainability	5, 34, 35, 36, 37, 38, 39, 41, 42, 43, 44, 51, 52, 53	Promote the transformation of green travel mode. Initiatives cover optimizing multi-modal public transport, developing slow-traffic systems, and installing green-supporting facilities.
Fairness	33, 45, 46, 47, 54, 55, 56, 57, 58, 59, 60, 62, 64, 67, 68, 69, 70, 72	Ensure safety, order and balanced service. Measures include rectifying non-motor vehicle parking and illegal vehicles, strengthening traffic management in key areas, carrying out safety publicity activities, and eliminating safety hazards to reduce the occurrence of accidents.

5.2. Qualitative Analysis

5.2.1. Efficiency Perspective: Efficiency Improvement and Spatial Bias

Policy design is deeply driven by the logic of maximizing efficiency, and a number of measures(Table 1: Efficiency) aim to reduce travel costs in a broad sense. For example, Measure

7 requires the "synchronous planning, construction and operation of track and branch line facilities", and Measure 32 further shortens the time by optimizing transfer, both of which are in line with the classic cost minimization strategy.

The empirical model shows that the average travel cost of the hub core area has dropped significantly from about 1,209 yuan to about 865 yuan, but the benefits are highly concentrated in the hub area [27], reflecting the spatial bias of policy resources. This is consistent with the theory of multi-center urban structure: strong hubs often obtain disproportionate resources to maximize efficiency [24].

The resource allocation of priority construction also reflects the hub center strategy. For example, the southern extension of Line 6 and the "station city integration" both give priority to covering high-priced and high-demand areas. Although this cost-effective-oriented efficiency strategy optimizes the core hub, it may damage the sustainability of the overall structure and the development of the surrounding areas [7], highlighting the spatial imbalance in institutional design.

5.2.2. Sustainability Perspective: Structural Transformation and Inequality

From the perspective of sustainability, the policy mainly reflects the "improvement" element in the "Avoidance-Transfer-Improvement" (ASI) framework. By improving subway services, optimizing hub connections and promoting slow transportation facilities(Table 1: Sustainability), the policy has effectively promoted the "transfer" of travel from private transportation to public transportation.

However, the "evasion" strategy is progressing slowly. Although the policy mentions the integration of station cities and the balance of work and housing, the specific behavioral guidance is weak, and there is a lack of substantive measures to reduce unnecessary commuting through mixed land development and travel demand management [1]. Empirical analysis reflects this structural imbalance: although sustainability has improved as a whole, the growth of non-core areas lags significantly behind that of the hub core areas, indicating the lack of effective "avoidance" measures [14].

Long-term reliance on "improvement + transfer" and neglect of "avoidance" will restrict the real structural transformation. Focusing only on service optimization and technology upgrading, but not giving priority to reducing travel from the demand side will weaken the potential for deep-seated change at the institutional level.

5.2.3. Critical Spatial Justice Perspective: Increasing Spatial Inequality

From the perspective of procedural justice, there are obvious shortcomings in the governance process: the action plan emphasizes "land acquisition", "node improvement" and "responsible units"(Table 1), but lacks transparent public participation or community consultation mechanisms(Table 1: Fairness). This kind of technocratic decision-making takes administrative rationality above social needs [26].

In terms of relationship justice, the policy is obviously inclined to the residents of the hub area, making it the main beneficiary group, while the residents of the peripheral or non-hub area are marginalized. This difference is not only reflected in the configuration of functional facilities, but also in the deep asymmetry of resource allocation and participation channels [25].

On the whole, the policy strengthens the privileged status of certain "advantageous" groups (hub residents) through its design and governance mechanism, but does not provide institutional guarantees for other groups. As Amorim et al. (2025) emphasized, transportation equity is not only about efficiency and accessibility, but also involves social structure, decision-making participation and fair participation mechanisms - vulnerable groups such as low-income families and the elderly are often excluded from planning participation, thus losing the right to travel [3].

The Gini coefficient rose from 0.151 to 0.171, further confirming the lack of fairness: policy logic gives hub residents privileges, while vulnerable groups lack institutional protection. The fundamental problem of equity, "who benefits", has not been fully resolved.

The Tongzhou case shows that the success of large-scale transportation infrastructure projects should not be measured only by efficiency or structural transformation indicators. Spatial fairness must become the core evaluation dimension - the service object and purpose of the infrastructure is as important as its operational efficiency.

6. Conclusion and Implications

6.1. Conclusion

Based on the framework of efficiency, sustainability and spatial equity, this study evaluates the optimization policy of Beijing Tongzhou Metro Line 6. It is found that: (1) the policy significantly reduces the overall travel cost, but the benefits are concentrated in the hub core area; (2) Sustainability is improved through "improvement" and "transfer" strategies, but the "evasion" measures are insufficient, and the accessibility and work-living balance improvement of non-core areas are limited; (3) Technical administrative means strengthen the benefits of core areas, marginalizing the interests of surrounding residents, insufficient public participation, uneven distribution of resources and rising Gini coefficient all indicate the decline in spatial equity.

6.2. Policy Implications and Research Limitations

Policy Enlightenment: Infrastructure benefits need to take into account efficiency and spatial equity. In the short term, a transportation equity fund can be set up to support transportation services in the surrounding areas; in the long term, fair indicators such as the accessibility Gini coefficient should be included in the planning and evaluation system, and a public participation mechanism should be established. At the same time, travel demand management tools can be introduced to optimize the travel structure.

Research limitations: The existing analysis is mainly based on the empirical analysis of policy texts and second-hand data, and lacks in-depth investigation of the life experience of different groups. Follow-up research should adopt methods such as interviews and field observation to explore the fit between planning and actual needs, and deepen the understanding of procedural equity and relationship equity.

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