

Research on the Impact and Strategies of Rail Transit Network Integration in the Context of Metropolitan Area Development: A Case Study of the Wuhan Metropolitan Area

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Abstract: The metropolitan area is one of the key focal points in the construction and development of China's new urbanization. Urban integration is an emerging trend in metropolitan areas. This paper explores the traffic demand characteristics and economic aspects of rail transit within metropolitan regions and argues that the construction of an integrated urban rail transit network is an effective approach to support their development. Rail transit in metropolitan areas offers both technical and economic advantages, improving the efficiency of time and space resource utilization, fostering economic cooperation, and ultimately contributing to an integrated development model. However, the integration of rail transit networks faces several challenges, including road network planning, technical standards, and operational organization. Using the Wuhan metropolitan area as a case study, this paper analyzes the challenges of rail transit network integration and proposes strategic solutions for development.

Keywords: Rail transit; Metropolitan area; Rail network integration; Urbanization

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1. Introduction

The metropolitan area is a focal point in China's new urbanization efforts. Tsinghua University's China Institute of New Urbanization and other institutions predict that China will form 34 metropolitan areas in the future^[1,2]. Transportation is a fundamental factor influencing the development of metropolitan areas. Given the dense population, industrial concentration, vast geographical expanse, and limited commuting time in current metropolitan areas, rail transit has emerged as the dominant mode of transportation for the majority of metropolitan areas and city clusters worldwide. The National Development and Reform Commission has explicitly proposed to "build metropolitan areas on the track" by promoting the integration of trunk railways,

intercity railways, suburban railways, and urban rail transit networks^[3].

The Wuhan metropolitan area primarily refers to the contiguous development area of four cities—Wuhan, Ezhou, Huanggang, and Huangshi—and serves as the economic center of Hubei Province. As of 2023, the total population of this region accounts for approximately 40% of the province’s population, while its GDP represents about 47.1% of Hubei’s GDP. The 2022 Wuhan Metropolitan Area Development Plan has been officially approved by the National Development and Reform Commission. Since then, Hubei Province has set development goals aimed at “continuously improving the level of infrastructure connectivity” within the metropolitan area.

In summary, this article addresses the following key issues: why and how rail transit has become essential to metropolitan area development, the challenges faced in the “four-network integration” of the Wuhan metropolitan area, and potential solutions to these challenges.

2. Literature review

The concept of a metropolitan area originated in the United States, and its definition varies across different regions. However, it is generally understood that a metropolitan area is a spatial unit that transcends urban administrative boundaries and is characterized by close interconnections. Residents of central urban areas and suburban regions within the metropolitan area share similar infrastructure and public services, creating an “urban integration” effect. Integration is a feature of a certain stage of urbanization, representing a development strategy designed to overcome the constraints of traditional administrative divisions and local protectionism, thus fostering sustainable regional cities. Metropolitan areas are not only the “strong core” driving urban agglomeration development, but their development also contributes to regional integration^[4,5]. In short, metropolitan areas function as hubs for population and resource aggregation, breaking through administrative boundaries to promote complementary advantages, resource sharing, and win-win cooperation. High-quality shared services, particularly transportation networks, are essential for metropolitan area development.

Foreign scholars have long studied the relationship between rail transit and urban interactive development, concluding that the comprehensive development of rail transit hubs is an effective way to promote urban growth^[6,7]. Numerous domestic scholars have also researched urban rail transit network integration. For instance, Tao Zhixiang proposed the “four-network integration” planning concept based on the theory of “space, demand, and supply”^[8]. Wang Guan and others advocated for the planning concept of “forming a network in the main city and connecting lines in the new city,” emphasizing the need for a multi-modal network that integrates various transit networks^[9]. The China Railway Fourth Survey and Design Institute highlighted the importance of optimizing and improving railway standards to advance the integrated development of the four networks^[10]. However, most previous studies have focused on individual aspects of rail transit or metropolitan area development, with limited research on the mechanism by which rail transit impacts metropolitan area development.

3. Composition and economic characteristics of urban rail transit networks

3.1. Composition of urban rail networks in metropolitan areas

The existing rail transit lines in China consist of four types: mainline railways, intercity railways, suburban railways, and urban rail transit. These systems provide transportation services with different operational modes,

spatial ranges, and speeds, as shown in **Table 1**. Due to differences in technology and organization, independent operational systems are more convenient to manage but increase the number of travel links and the time required for users. Both practice and research have demonstrated that an imperfect transportation network is a significant obstacle to the development of metropolitan areas.

Table 1. Composition of China’s urban rail transit system

Track type	Service scope	Design speed (km/h)	Average station spacing (km)	Line length (km)
High-speed railway	International, national, regional	250–350	30–60	> 300
Conventional railway	National, regional	< 160	10–50	> 300
Intercity railway	Metropolitan area	120–200	5–20	> 100
Urban (suburban) railway	Urban circle, Central urban area	100–160	3–7	30–80
Urban rail transit	Central urban area	80–100	0.5–1.0	< 40

3.2. Economic characteristics of rail transit

Rail transit is currently the most efficient mode of urban transportation. It offers high speed, large transportation capacity, and low energy consumption, while also possessing industrial characteristics such as network economies, asset specificity, and positive externalities. Due to these technological and industrial economic features, rail transit has notable spatiotemporal economic advantages, including spatial monopoly, spatiotemporal economies of scale, and the spatiotemporal tunnel effect (as shown in **Figure 1**).

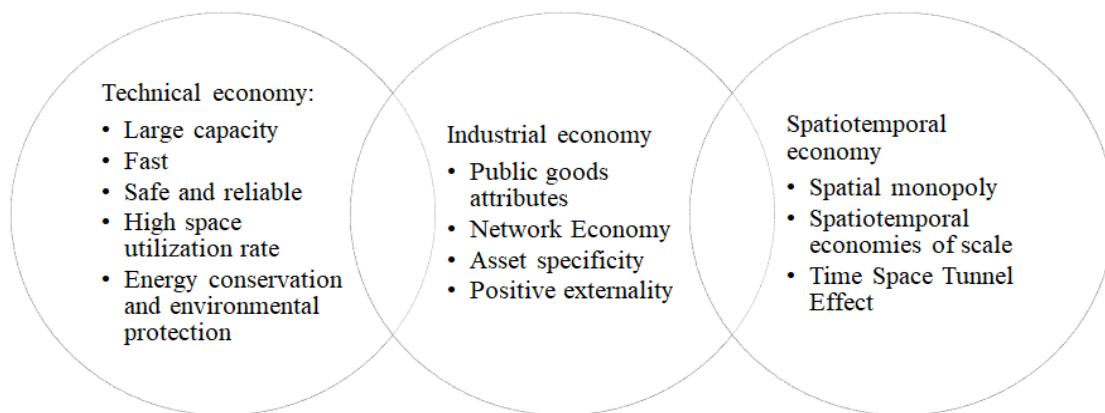


Figure 1. Economic characteristics of rail transit

Given these economic characteristics, rail transit’s benefits can support spatial expansion and high-density development along its routes. Rail transit attracts resource aggregation and enhances its integration with urban space, improving accessibility within the region. For users, rail transit provides high accessibility. Increased accessibility will also influence user preferences, encouraging them to choose rail transit hubs for living or working and rely on rail transit as their primary mode of transportation.

The “Guiding Opinions of the National Development and Reform Commission on Cultivating and Developing Modern Metropolitan Areas” emphasize the need to comprehensively consider the layout of urban

rail transit networks and establish commuting zones with rail transit as the backbone^[3]. Urban rail transit plans should be developed in regions where conditions allow, promoting the integration of trunk railways, intercity railways, suburban railways, and urban rail transit networks. In August 2020, China National Railway Group Co., Ltd. issued relevant guidelines proposing the integration of multiple rail transit networks. Several urban areas, including Beijing, have since proposed plans and strategies for the integration of the four networks.

4. Analysis of the impact of rail transit on the development of metropolitan areas

Experience shows that with reasonable transportation support, metropolitan areas can operate efficiently and generate agglomeration economic effects, as seen in places like Tokyo and Hong Kong, which represent some of the most efficient urban areas in terms of public transportation. Urban challenges, often referred to as “urban diseases,” are typically caused by the lack of coordination between transportation development and the urbanization process.

4.1. Characteristics of transportation demand in metropolitan areas

Metropolitan areas concentrate a large number of people and industries, generating agglomeration economic effects. During this agglomeration process, spatial expansion also occurs, resulting in high transportation demand and complex travel needs. The following characteristics are key:

- (1) Increasing demand: A large concentration of economic resources and activities within metropolitan areas leads to continuously increasing passenger flow, both within internal regions and between internal and external areas.
- (2) Longer commuting distances and times: Metropolitan areas typically have a multi-center structure, where the central area retains a strong economic and functional core. Centripetal commuting remains the dominant transportation demand, and as the area expands, the distance between the center and the periphery increases, leading to longer average travel distances.
- (3) Complex and diverse transportation needs: The demand for transportation varies and includes internal commuting, business travel, leisure, and entertainment trips. As a result, the transportation network must offer diverse, hierarchical, and efficient services.

4.2. Impact of the rail transit network on the spatiotemporal space of metropolitan areas

Given the economic characteristics and accessibility advantages of rail transit, it provides significant benefits in terms of spatial organization, travel time, and economic efficiency within urban areas.

4.2.1. Impact on urban space and time utilization

The influence of rail transit on space utilization in metropolitan areas includes the following:

- (1) Efficient use of transportation space: Rail transit offers the highest capacity per unit of time and uses less land per capita compared to other land-based transportation modes.
- (2) Three-dimensional expansion of socio-economic space: Rail transit supports horizontal expansion, as well as the development of underground and above-ground spaces, enabling metropolitan areas to expand in three dimensions and improve land use efficiency.
- (3) More rational layout of urban functional spaces: As resources and urban functions cluster around the rail network, the functional layout of metropolitan areas becomes more balanced. For example, cities

like Beijing use rail transit to support the development of satellite cities and alleviate pressure on central areas.

4.2.2. Impact on urban time utilization

Rail transit affects time usage in metropolitan areas in two key ways:

- (1) Reduced commuting time: The average speed of rail transit is about twice that of road buses, offering stable and reliable travel times. In addition, the development of rail routes reduces travel distances and time by minimizing the dispersion of functional spaces.
- (2) Increased value of travel time: Due to the development of rail hubs, the travel process not only serves transportation needs but also fulfills various daily needs, such as leisure, dining, and social activities.

4.2.3. Impact on the spatiotemporal relationship of metropolitan areas

The impact of rail transit on the spatiotemporal relationships within metropolitan areas includes three aspects:

- (1) Optimized travel chain: The spatial distance between economic entities can be converted into time distance T through transportation networks, expressed by the travel time T_r of vehicles (travel distance divided by speed). Considering connection time T_i (including walking, waiting, and transfers), and uncertainties such as weather, congestion, and accidents T_u , the total travel time distance is shown in the formula $T = T_r + T_i + T_u$. Compared to road buses, the connection time in rail transit is more predictable and stable, with fewer external disruptions and almost no congestion, low accident rates, and minimal uncertainty. The clustering of functions around rail networks helps create stable spatiotemporal relationships.
- (2) Improved efficiency of space-time conversion: Relying on the closed, specialized, fast, and stable characteristics of rail transit, transportation efficiency is improved, facilitating cooperation and communication among different economic entities within the metropolitan area.
- (3) Facilitation of economic relationships: High-density development around rail hubs, with concentrated personnel, resources, and functional areas, promotes economic cooperation and helps establish diverse temporal and spatial relationships.

4.3. Mechanism of the impact of rail transit on metropolitan area development

Rail transit alters the spatiotemporal dynamics of metropolitan areas, enhances the accessibility of spatial and user resources, and attracts the aggregation of economic resources. Additionally, it influences the dimensions and density of land use, fostering the orderly expansion and three-dimensional development of urban spaces, which supports integrated urban development. Economic growth creates new demands, driving a continuous cycle of interactive development between rail networks and metropolitan areas^[11]. This operating logic for sustainable metropolitan development is illustrated in **Figure 2**.

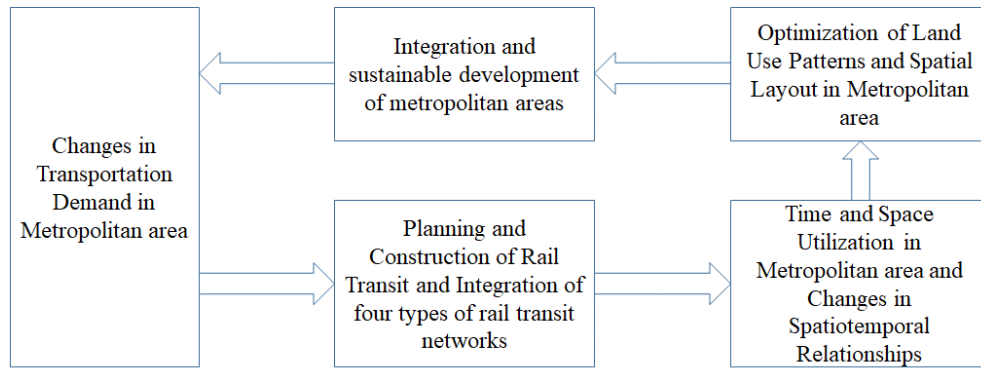


Figure 2. Relationship between rail transit networks and metropolitan area development

5. Existing problems and integrated development strategies of the rail transit network in the Wuhan metropolitan area

5.1. Issues in the integration of four networks in the rail network

The Wuhan metropolitan area has initially established a multi-level rail transit system, including ordinary railways, high-speed railways, intercity railways, suburban railways, and urban rail transit, achieving connectivity of one to two hours between Wuhan and some surrounding cities. However, several development issues remain:

The most evident issue is that the integrated development of the multi-level rail transit system in the metropolitan area is incomplete. The division of labor between some intercity and high-speed railways from Wuhan to nearby cities is unclear, and some project resources are underutilized. This results in weak passenger flow attraction, severe operating losses, and significant financial pressure on the government.

Additionally, the rail transit network in the Wuhan metropolitan area lacks proper connectivity, leading to long commuting times. Differences in planning, construction, and operational management, combined with administrative boundaries, create inefficiencies in connecting different types of lines. Some mainline railway stations are located far from urban functional areas, resulting in insufficient intercity railway services for the region. The urban (suburban) railway network has few lines and low density—currently, only the Wuhan-Xiaogan and Wuhan-Huanggang urban (suburban) railways are operational. Moreover, some urban rail transit lines extend too far into suburban areas, increasing construction and operational costs. Transfers between different networks are inconvenient, with total travel times exceeding 1.5 to 2 hours in some cases.

An imperfect management system also hinders the integration of Wuhan’s metropolitan rail network^[12,13]. Challenges include negotiating the renovation of existing railway lines and improving income settlement mechanisms among stakeholders. The low passenger flow for suburban trains discourages railway enterprises from participating actively. Differences in management entities and administrative boundaries further complicate the development of urban (suburban) railways.

Due to the lack of an efficient rail transit network, the Wuhan metropolitan area’s transportation efficiency is low, and its urbanization effects are not as pronounced.

5.2. Strategy for the integration of the four rail transit networks

The planning, construction, and operational management of a rail transit network require coordination across

various aspects, such as facility design, technology, organizational structure, and policies. The specific strategies for integration are as follows:

- (1) Prioritize planning and integration: Develop a network integration plan led by the metropolitan area. Reserve interfaces and land to connect and supplement different networks. Ensure compatibility between various rail lines, including shared facilities and equipment, to avoid resource waste ^[14].
- (2) Optimize rail transit hub connectivity: Improve transfer efficiency and promote the comprehensive development of Transit-Oriented Development (TOD) centered around rail hubs. This not only meets transportation needs and ensures efficient hub operations but also caters to other social needs during travel, enhancing the economic and social benefits of the rail network.
- (3) Create technical conditions for network integration: Establish common technical standards, integrated infrastructure planning, shared facilities, and shared operational information. Through collaborative innovation, address technical barriers in key areas, such as equipment, power supply, and signal interconnection.
- (4) Promote service integration: Coordinate multi-network operational models, unifying management processes within the metropolitan rail network. Provide comprehensive transportation information services, including push notifications and queries.
- (5) Improve operational mechanisms: Develop and implement standards and specifications for the rail transit industry. Establish a coordination mechanism between national and local railways, promote joint development between rail transit and surrounding land, and issue relevant supporting policies.

6. Conclusion

A metropolitan area is a form of urbanization that concentrates economic resources, generating agglomeration effects and diversified transportation demands. Such areas require a large-capacity, reliable, and environmentally friendly transportation network. Compared to road traffic, rail transit is an effective solution for addressing the specific transportation needs of metropolitan areas. Rail transit improves the efficient use of space and time resources and enhances the construction and optimization of spatiotemporal relationships.

Although the metropolitan area already has a diversified rail transit network, further integration is necessary to improve service levels and better meet urban transportation needs. Achieving integrated rail transit operations requires adjustments and collaboration in infrastructure, technical equipment, service organization, and policy systems, beginning from the planning and construction stages—particularly for metropolitan areas like Wuhan.

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References

- [1] Yin Z, Yuan X, 2019, China Metropolitan Area Development Report 2018. Tsinghua University Press, 201910.
- [2] Pan Z, 2020, Accelerating the Construction of a Multi-level Rail Transit System in the Metropolitan Area. *Macroeconomic Management*, 20201108.
- [3] National Development and Reform Commission, 2019, Guiding Opinions of the National Development and Reform Commission on Cultivating and Developing Modern Metropolitan Regions.
- [4] Wang D, 2021, Exploring the Transformation Model of Chinese Urban Agglomerations Towards High-Quality Development. *National Governance*, 2021(2): 9–13.
- [5] Fu J, Geng D, Yang D, 2020, A Study on the Development Review and Countermeasures of the Integration of China's Five Major Metropolitan Areas. *Regional Economic Review*, 2020(6): 101–110.
- [6] Knight RL, 1980, The Impact of Rail Transit on Land Use: Evidence and A Change of Perspective. *Transportation*. 1980, 9(1): 3–16. <https://doi.org/10.1007/BF00147814>
- [7] Bertolini L, Spit T, 1998, *Cities on Rails: The Redevelopment of Railway Station Areas*. Routledge, London.
- [8] Tao Z, 2020, Theory and Practice of “Four-Network Integration” Planning for Urban Rail Transit. *Traffic Governance and Spatial Reconstruction – Proceedings of the 2020 Annual Conference on Urban Transport Planning in China*, 202009.
- [9] Wang G, Yuan Z, Dai Q, 2022, Regional Traffic Planning of Wuhan High-speed Rail Hub under the Mode of Station-city Integration – Taking the Newly-built Hanyang Station as an Example. *Railway Economic Research*, 2022(S1): 45–48.
- [10] China Railway Siyuan Survey and Design Group Co., Ltd., 2023, Optimizing and Improving the Railway Standard System to Promote the Integrated Development of Four Networks. *Railway Technical Standards*, 5(4): 41–44.
- [11] Wang X, 2017, Research on the Interactive Evolutionary Relationship between Rail Transit and Metropolitan Morphology – Based on the Perspective of Spatio-temporal Economics, dissertation, Beijing Jiaotong University.
- [12] Yu X, Zhang L, 2021, Research on the Integrated Development of Beijing's Rail Transit and Railway Four Networks. *Modern Urban Rail Transit*, 2021(1): 20.
- [13] Wei J, 2021, Promoting the Integrated Development of the Wuhan Metropolitan Area. *Hubei Provincial Political Consultative Conference*, 2021(1): 24.
- [14] He L, Chen L, 2022, Reflections on the Development Planning of “Four-Network Integration” for Rail Transit. *Traffic and Transportation*, 2022(7): 153–158.

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