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Research on Development Requirements, Challenges, and Pathways for the Integrated Development of Urban Rail Transit, Bus, and Non-Motorized Transportation Networks

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Abstract: Under the background of the rapid development of urban rail transit and shared bikes, the passenger flow of urban bus continues to decline. It is urgent to promote the integration of urban rail transit, bus and slow traffic systems to form an integrated public transportation system. Taking typical cities as examples, this paper analyzes three significant changing trends of urban traffic passenger flow characteristics and the demand characteristics of the integration of the three networks in China. Based on the travel demand characteristics of the integration of the three networks in China and combined with international experience, this paper proposes the development connotation focusing on the whole process of people's travel, and points out that there are problems such as insufficient overall planning and construction coordination and difficult integration of operation services in the "Integration of the three networks" in China. Finally, this paper proposes the development strategies and paths of the integration of the three networks are defined from five levels: planning, standards, mechanisms, facilities, networks and services.

1. Introduction

Since the end of the 1980s, with the improvement of urban public transport policies and the rapid development of urbanization, urban transport has entered a period of rapid development. By the end of 2023, a total of 55 cities in China had opened and operated 306 urban rail transit lines, with an operating mileage of more than 10,000 kilometers and a passenger volume of 29.44 billion person-times. In contrast, the urban buses passenger volume has shown a rapid decline in recent years(see from Figure 1). On the one hand, urban rail transit has diverted part of the bus passenger volume. On the other hand, other transport modes such as shared bicycles have also diverted buses passenger flow the same time. There are large differences in bus passenger transfer directions in different types of cities. The passenger transfer proportion from bus to rail transit reached 23.84% in megacities with rail transit especially, and the transfer proportion from bus to bicycle is the highest in megacities (see from Table 1). In the context of the rapid development of urban rail transit and shared bicycles, it is

urgent to promote the integration of urban rail transit, buses and slow traffic to form an integrated public transport system.

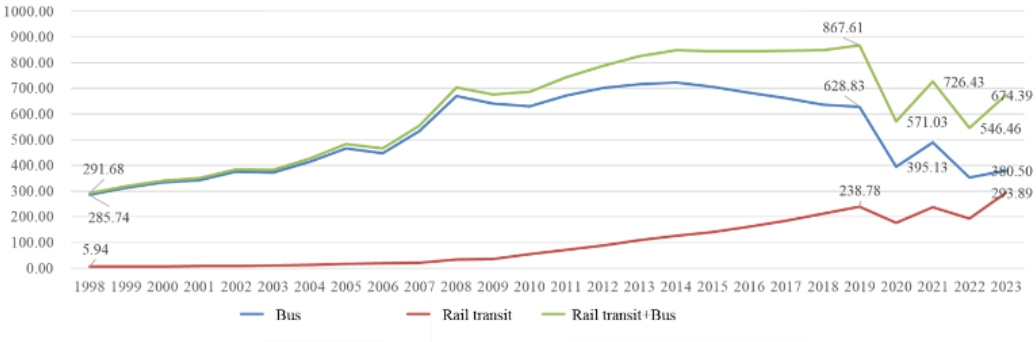

Figure 1 Trend of national bus passenger volume from 1998 to 2023 in China (Unit: 100 million person-times)

Data source: Ministry of Transport, Transportation Statistical Bulletins over the years.

Table 1 The passenger transfer proportion from bus to other urban transport modes.

Transfer modes	Megacity	Megalopolis	I Big City	II Big City	Medium City
Still bus	27.85%	32.11%	34.33%	36.54%	46.73%
Bus to rail transit	23.84%	11.08%	12.61%	——	——
Bus to car	11.50%	10.22%	13.04%	14.03%	12.45%
Bus to electric bike	6.87%	16.86%	9.87%	15.09%	10.18%
Bus to bike / shared bike	3.07%	3.27%	2.87%	3.42%	2.09%
Bus to taxi/online ride-hailing services	1.87%	0.95%	4.59%	1.59%	1.91%
Bus to motorcycle	1.30%	1.33%	1.52%	1.36%	3.82%
Bus to other modes	3.33%	5.23%	3.97%	4.18%	4.09%
Didn’t often take bus before	20.35%	18.95%	17.20%	23.79%	18.73%

Data source: Survey data on Major Project of the Chinese Academy of Engineering

In September 2019, the State Council of China issued the “Outline for Building a Strong Transportation Country”, it clearly proposing to "promote the construction of urban public transport facilities and strengthen the connection between urban rail transit and other transport modes". In April 2024, the State Council of China issued the "Comprehensive National Transport Network", it clearly proposing to "place more emphasis on overall coordination and promote the coordinated and integrated development of various transportation modes". The "14th Five-Year Plan for Comprehensive Transportation Services" clearly proposes that "the megacities and large cities will establish the dominant position of rail transit in the urban public transport system and strengthen the urban public transport system integrating conventional buses, rail transit and non-motorized traffic networks by 2025".

With the continuous improvement of urban living standards, the travel demand levels of residents are constantly upgrading [1]. The "Manual of Public Transport Capacity and Service Quality" regards the availability, comfort and convenience of bus services as the key factors which determine whether residents choosing public transport to travel or not. The German Transport Enterprise Alliance takes the whole travel time from the departure point to the destination during passengers' travel as an important factor to evaluate service level of urban public transport.

Therefore, urban public transport should adapt to the trend of travel demand upgrading and change from meeting basic travel to providing integrated, fast and high-quality travel services.

2. Changing Trends of Supply and Demand in urban Public Transport

2.1 Characteristics of Urban Transport Passenger Flow

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With the deepening of the new urbanization process and the multiple impacts of new technologies and new business forms, travel characteristics of urban residents show three significant changes:

(1) From the perspective of travel structure, the dominant status of urban public transport has declined in motorized travel modes, and the bicycle travel mode has gradually returned.

Through Beijing traffic structure changes in recent years, urban public transport ratio reached at 44.05% peak in 2017, but declined to 37.91% in 2023. The bicycle travel ratio from 62.7% in 1986 declined to 16.71% in 2017, as improving the comprehensive management and road condition of slow traffic system, promoting the construction of public bicycle system, the bicycle travel ratio rise again and reached 23.3% in 2023(see from Figure 2).

(2) From the perspective of travel purpose, it has changed from a simple travel chain dominated to a complex travel chain with multiple travel purposes dominated.

During the period when manufacturing accounted for the main form of urban employment, commuting travel was the main travel purpose of urban residents. For example, the proportion of commuting travel in Shanghai exceeded 65% in the 1980s and 1990s [2], but had decreased to 52.12% [3] by 2015. With the continuous upgrading of the urban industry and improvement of people's living standards, the travel demands for leisure, entertainment, business and other living types have gradually increased and diverse. It can be seen from the mode structure of travel purposes of Beijing residents in 2019, that the public transport ratio in commuting travel is high and accounting for about 50%, and elastic travels such as leisure and life are more choose individualized transport modes, with the highest proportion of non-motorized modes, followed by car modes.

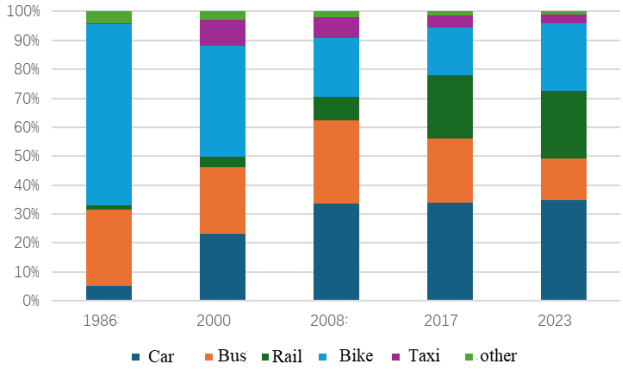

Figure 2 Composition of travel modes in Beijing over the years (excluding walking)

(3) From the perspective of travel time consumption, with the increase of the commuting radius, the commuting time consumption will be increasing with the of the distance increased.

According to relevant research [4], the commuting space radius of 41 out of 45 major cities increased during 2019 to 2023, and the commuting population in megacities and large cities also showed a trend of "increase at both ends and decrease in the middle", the population of short-distance commuting increased, and the population of long-distance commuting of "15 km - 25 km" and "25 km and above" also increased. Among all cities with urban rail transit operated, 12% of the commuting population still face a one-way commuting time of more than 60 minutes every day. Beijing is the city with the largest number of extreme commuting population, with a commuting proportion of more than 60 minutes as highest as 28%. The expansion of the commuting travel range brings new challenges to the public transport system.

2.2 Demand Characteristics of the Integration of the Three Networks

From the perspective of the urban rail transit stations connection travel purpose, taking Hefei as an example, commuting for work is the main purpose of urban rail transit stations connection travel which accounting for 40%, followed by connection travel for leisure/entertainment and school. Commuting people have higher requirements for the urban rail transit connection and pay more attention to the humanized service of integrated connection.

From the perspective of urban rail transit stations connection travel modes, according to relevant surveys, the urban rail transit connection characteristics of "1-kilometer by walking, 3-kilometer by cycling and 5-kilometer by bus" are obvious. Walking to urban rail transit basically shows a decreasing trend from the city center to the outside, while the connection proportions of non-motor vehicles and buses first increase and then decrease(see from Table 2). Therefore, the urban rail transit stations connection environment of walking and non-motor vehicles is worthy of attention. The urban rail transit stations connection demands of non-motor vehicles and buses in surrounding areas are obvious, and it is necessary to focus on encrypting bus connection lines and optimizing non-motor vehicle parking areas. The urban rail transit stations connection demand of electric bikes at external transport station and other transfer stations is relatively low, and it is necessary to focus on optimizing bus connection and reducing the deployment of shared electric bikes.

Table 2 Sharing Rates of urban rail transit stations connection travel modes in different regions

Location	walk	bike	electric bike	bus	car	taxi	other
central station	57%	12%	24%	2%	1%	2%	2%
transfer station	46%	21%	15%	4%	6%	6%	1%
surrounding station	30%	23%	35%	7%	1%	1%	1%

Data source: Evaluation of the Current Situation of the Planning for the Integration of Rail, Bus and Non-motorized Traffic in Hefei.

From the perspective of the urban rail transit stations connection distance, the connection distance of Hefei rail transit stations is mainly 1 km which accounting for about 66%, and the farther connecting to rail transit station, the lower connection passenger flow. More than 80% of the shared bicycle rides connection distance with "cooperative" urban rail transit stations in Beijing are within 1.5 kilometers(see from Figure 3).

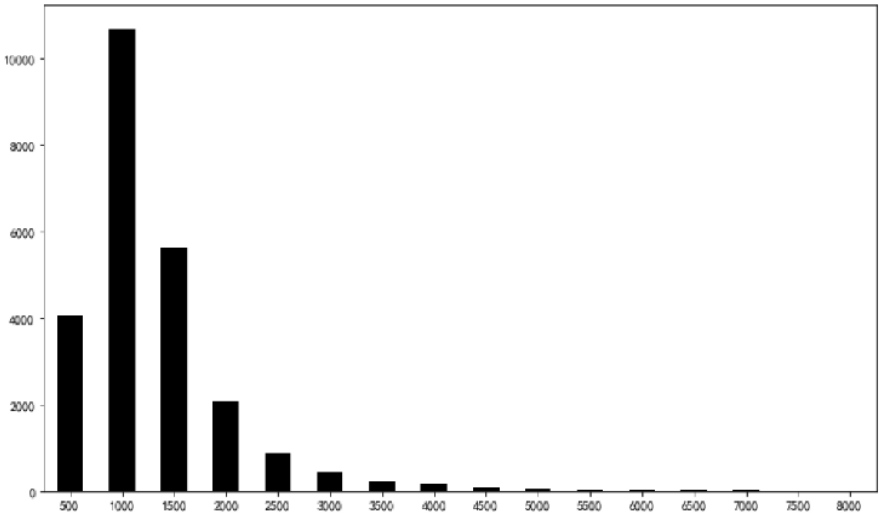

Figure 3 Distribution of cycling distances starting from urban rail transit stations in the morning peak of "Urban Public Transport + slow traffic" trips.(Unit: meter)

3. Original Dilemmas and Connotation Analysis of the Integration of the Three Networks

3.1 Connotation Characteristics of the Integration of the Three Networks

In terms of concept, the integration of the three networks is to realize the network integration of urban rail transit, buses and slow traffic, systematically construct a "one-network" pattern. From the perspective of the starting point and essence of the integration of the three networks, it is to realize more convenient and efficient flow of people in future urban transport and provide whole-travel services that meet differential and diversity demands.

Combined with international experience, the understanding of the development connotation of the integration of the three networks can be divided into two aspects: service function and support environment. 1) The integration of service functions: taking travel demand as the core orientation, maximizing the overall allocation of resources, coordinating station and line in planning, matching construction progress, and coordinating transportation capacity input, the gradually realizing a service system of "one-systems, one-network and one-ticket", providing efficient, convenient, reliable and integrated urban public transport services, which fully meeting the complex and differentiated demands of passengers groups. 2) The integration of the support environment: Promote innovation and integration in operation management and tickets fare systems, establish a supporting legal, regulatory, standard system and a coordinated working mechanism. Therefore, the integration of the three networks is to enable residents to experience integrated transportation services through efficient management of public transport, including coordination in planning and design, synchronous and overall construction, connection and coordination in operation services, and overall planning and guarantee in operation management mechanisms and systems. It includes the integration of networks and hub facilities, as well as the integration of operation services and institutional mechanisms.

3.2 Dilemmas Facing the Development of the Integration of the Three Networks

Cities such as Shenzhen, Beijing and Shanghai in China have carried out preliminary explorations on the integration of the three networks. However, due to the involvement of multiple levels of departments, multiple interest subjects and multiple professional fields, the problems are complex and the reasons are numerous. From the perspective of problem manifestations and results, they mainly include the following aspects:

(1) The overall planning and construction coordination of the integration of the three networks is insufficient.

Urban rail transit, buses and slow traffic have different functional positioning and service scopes, but they also overlap in function. The setting of relevant planning and construction indicators focuses on construction and neglects services, and lacks overall planning of the public transport system from the perspective of the entire travel chain.

(2) There is a lack of an integrated operation mechanism, and it is difficult to integrate operation services.

The management departments of urban rail transit, buses and shared bicycles are mainly managed by transport manager departments, but generally the operations belong to different entities. The coordination motivation of each operation entity is insufficient, and they separately prepare operation plans according to their own needs. There is a lack of coordination in operation scheduling, transfer information services, payment systems and fare mechanisms, and the integration of the three networks is difficult and the integration of operation services is not deep. For example, the bus connection with urban rail transit on first and last trains is unreasonable, the waiting time for passengers to transfer is long, and a mileage-based combined fare mechanism has not been established, affecting the overall transportation efficiency and service quality of urban transport.

(3) The functional levels of the urban public transport network need to be further optimized.

In recent years, with the gradual formation of urban rail transit networks, the passenger flow of urban rail transit in cities such as Beijing, Shanghai, Shenzhen and Wuhan has gradually occupied the dominant position in urban public transport, the bus position has gradually changed from the main body to the network function. Due to buses involve many factors and have a wide social impact, so it is difficult to optimize and adjust them. Generally, urban rail transit diverts 15% of the passenger flow of bus lines with 3 co-linear stations, 25% of the passenger flow of bus lines with more than 7 stations. There are 38 bus lines in Hefei whose overlapping length with the existing urban rail transit network is more than 3 kilometers, accounting for 13% of the total urban lines.

(4) The integrated connection of urban public transport transfer nodes is not smooth.

Due to reasons such as insufficient planning foresight, different construction sequences and lack of coordination mechanisms, the integrated connection of hub nodes is insufficient. In particular, the construction and operation of urban rail transit belong to the construction management department and transportation management departments respectively, the transfer connection facilities are not synchronously equipped in the site planning and construction, and the integrated design of transfer facilities in the hub station is lacking, that affecting the integration, efficiency and service improvement of urban public transport system. For example, among the 23 rail transit stations in Shanghai Yangpu District, only 2 bus hubs were set up. In Hefei, the proportion of 136 urban rail transit stations with no bus line service within 50 meters radius around the station is as high as 43%.

4. Strategic Path Selection for the Development of the Integration of the Three Networks

In view of the problems existing in the integration of the three networks, combined with domestic and foreign experiences and development connotations, the integration of the three networks is promoted from the levels of planning and design integration, institutional mechanism integration, hub integration, network integration and service integration to improve the urban public transport travel chain, whole-travel experience and the overall efficiency of urban public transport system.

4.1 From the Perspective of Planning Integration, Scientifically Position the Functions of Each Mode

According to relevant domestic and foreign research conclusions, urban rail transit serves a radius range of 30 kilometers, bus serves a radius range of 5 kilometers, bike serve a radius range of 3 kilometers and walk serves a radius range of 1 kilometer. The urban transportation systems travel behavior in Chinese large cities also have similar characteristics. The integration of the three networks effectively supports the urban functional layout by using different transport modes to serve different spatial scales with different operating speeds. Cities need to combine the urban spatial layout and spatial strategic requirements, and in accordance with the requirements of the “one blueprint, one plan and one mechanism” to develop the integrated planning of urban rail transit, buses and slow traffic, promote the efficient coordination of various transportation modes, and realize the optimal allocation of resources. A key objective within the strategic framework of the new round of National Spatial Planning compilation and implementation is to continuously strengthen the leading role of multi-level, integrated urban public transport and to promote its integration with the urban spatial structure.

4.2 From the Perspective of Design Integration, Formulate Standards and Specifications for the Integration of the Three Networks

In all aspects of the design, construction, completion and operation of public transport facilities, standardize the integration of the three networks by improving norms and standards, clarify key

elements such as connection distances, supporting facilities and accessibility, ensure the realization of the regulatory responsibilities of the transportation administrative department for the transportation functions of the facilities. In the process of design and construction, the implementation of the integration of the three networks should be promoted in stages. In the preliminary design stage, it is necessary to clarify the connection forms and technical specifications between stations and surrounding traffic; in the engineering design stage, establish and improve the integrated connection norms between hubs/rail transit stations and surrounding buildings, and strictly promote the implementation of facility integration construction in accordance with the norms, and determine the specific implementation plan of the integration of the three networks, covering specific work such as the layout of transfer passages, the supporting of accessibility facilities and the optimization of signage systems; in the trial operation stage, optimize the slow traffic system, bus stops and supporting facilities to ensure the implementation of the design results.

4.3 From the Perspective of Facility Integration, Build an Integrated Transfer Hub System

Firstly, the transfer efficiency of the bus hub directly affects the efficiency of the integration of the three networks. Therefore, the focus of facility integration is to build an integrated transfer hub system and strengthen the seamless connection of different transport modes. Considering that different types of bus hubs have different connection requirements, the design requirements for connection facilities should be different. It is recommended to classify bus hubs according to various factors such as urban rail transit connected, bus resources, travel demands and land use around stations.

Secondly, systematically improve the connection conditions of public transport transfer according to local conditions. For the renovation of existing stations, an integrated renovation measure toolbox can be formulated with reference to various planning requirements, standards and guidelines based on the principles of safety, priority and feasibility. A sustainable combined renovation plan can be formulated around five main aspects: improving transfer efficiency, improving transfer information guidance services, optimizing transfer auxiliary facilities, improving transfer environment and improving the station facilities of transfer bus stops. According to the problems existing in different stations, various spatial elements involved in transfer can be flexibly integrated, and a "one-station-one-plan" optimization and upgrading plan for transfer can be formulated according to local conditions.

4.4 From the Perspective of Network Integration, Differentiate the Allocation of Transportation Resources

On the one hand, the resources of buses should be arranged based on urban rail transit, and the network should be integrated in a differentiated manner in different regions. That is, the bus resources allocation in different regions should be different based on the service level of urban rail transit. The areas with high-density urban rail transit coverage should be classified as the first-class bus area, bus can be used as a supplement and the line network density can be appropriately reduced. The areas with low-density urban rail transit network should be classified as the second-class bus area, bus service should be strengthened as the main body.

On the other hand, a network revolution should be carried out from the network level. The priority is to merge bus, rail, and slow-traffic infrastructure into a single, efficient network. Firstly, the bus service around the passenger corridor must be strengthened. Through high-frequency departures, high-quality services and efficient connections, the operation efficiency of public transport in the backbone corridor can be improved. Secondly, a more clear structure of buses should be constructed according to functions, including backbone type line and functional lines, such as connection lines and commuter lines.

4.5 From the Perspective of Service Integration, Improve the Integrated Travel Experience

Firstly, establish a "one-way" travel information service platform based on the whole travel chain. The objective is to promote the integrated operation of multi-modal transport resources through market-oriented entities. To achieve this, we will pursue several key strategies: encouraging new service providers, establishing cross-modal data exchange and a unified payment platform, and advancing the multi-scenario application of Mobility-as-a-Service (MaaS)[5].

Secondly, strengthen the digital governance of buses. In the current development situation, the integration of the three networks for cities are complex projects, which requires a large amount of multiple data sources support to achieve refined data analysis and collaborative governance. Therefore, it is urgent to build a digital twin base, break data barriers, enrich the data system, deeply explore the travel characteristics and laws of different groups of people, especially accurately identify the transfer scale and transfer direction between different modes, build a precise intelligent bus system suitable for the operation of complex public transport networks, and provide precise and diversified services to improve service efficiency.

To achieve seamless intermodal transportation operations, it is essential to deeply integrate intelligent data platforms, collaborative sensing technologies, and unified payment systems. This involves establishing standardized API interfaces to consolidate multi-source transportation data (including real-time GPS positioning, ticketing systems, and passenger flow monitoring), while employing AI algorithms for dynamic scheduling optimization. The application of IoT sensors and 5G communication technologies enables precise tracking of vehicle and infrastructure status, thereby enhancing transfer efficiency. Simultaneously, a blockchain-based cross-operator payment platform supports seamless integration of various payment methods such as QR code scanning and NFC.

4.6 The Government Leads in Rule-Making, Operators Deliver Services, and The Public Provides Feedback, Forming a Closed Loop of “Planning-Operation-Optimization.”

As the top-level designer and coordinator, the government is primarily responsible for formulating policies and regulations (e.g., data-sharing standards, fare integration mechanisms), coordinating cross-departmental planning (e.g., synchronizing land-use approvals with transport infrastructure development), and providing financial support (e.g., subsidies for new energy buses). Its core mission is to eliminate administrative barriers and ensure a fair competitive environment.

Transport operators (e.g., bus companies, metro groups, and ride-sharing platforms) must facilitate technical integration (e.g., opening real-time data interfaces), optimize multimodal schedule coordination, and explore joint fare-sharing models. At the same time, they should dynamically adjust services (e.g., flexible bus routes) based on user feedback.

5. Conclusions

Promoting the integration of urban rail transit, conventional buses, and non-motorized transportation systems is an essential requirement for enhancing the high-quality development of urban public transport. The integration of transportation networks can significantly improve the accessibility of public transit, narrowing service gaps between urban-rural areas and different income groups to promote social equity. Efficient multimodal connectivity reduces travel costs, attracts more passengers, and enhances the system's financial sustainability. The future development of the three-network integration shall concentrate on three key aspects:Firstly, the creation of a "City on Rails" must address the evolving demands throughout the entire travel chain and optimize public transport supply and services accordingly.Secondly, safeguard measures should be established for the integrated planning, construction, and management of areas around rail transit hubs to effectively

enhance station-city integration.Thirdly, it is crucial to actively encourage local governments to establish a development mechanism for this integration in the new era, fostering a tripartite win-win situation for the city, public transport, and citizens.

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