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Optimization of the Urban Rail Transit Network in Zhengzhou Airport Economy Zone

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Abstract: As the main artery of urban transportation, rail transit plays the role of the main skeleton of public transport, which is not only a livelihood project to improve the quality of life for the public, but also a foundational project to improve the quality and competitiveness of the city. By analyzing the planning adaptability of the existing rail transit network in Zhengzhou, the necessity of rail transit network optimization in the Airport Economy Zone is demonstrated. Drawing on the development experience of urban rail transit systems both domestically and internationally, a three-tier and six-category functional hierarchy for the rail transit system in the Airport Economy Zone is proposed. A variety of methods are utilized to predict the scale of the rail transit network. The planning approach adheres to a tiered structure, prioritizing external connections before internal ones, and is guided by the optimization philosophy of strong external connections and internal systems. According to the optimization strategy of regional coordination, group integration, and service optimization, this paper proposes the optimization plan for express urban rail transit lines A and B, and regular lines, as well as suggestions on operational organization. The optimized scale of the rail transit network in the Airport Economy Zone is 264.6 kilometers, which connects critical nodes and central clusters, covering both primary and secondary passenger flow corridors. The optimization plan is of significant importance for the construction of an "Airport Economy Zone on Rails." **DOI:** 10.13813/j.cn11-5141/u.2024.0023-en

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The Zhengzhou Airport Economy Zone (hereinafter referred to as the Airport Economy Zone) is the only national-level aviation economic development pilot zone approved by the State Council. In September 2021, the Provincial Party Committee of the Communist Party of China (CPC) and the Provincial Government of Henan included four towns in Weishi County into the management scope of the Airport Economy Zone, expanding the administrative area from 415 km^2 to 747 km^2. In April 2022, the Provincial Party Committee of the CPC and the Provincial Government of Henan conducted a systematic restructuring and reform of the Airport Economy Zone with a forward-looking vision of 30 years, which further enhanced the spatial scale and development capacity, and made significant adjustments to the urban positioning and higher-level planning. Therefore, in response to the direction of urban spatial expansion and the trend of scale growth, and with a focus on enhancing radiation and coordinating internal and external development, it is imperative to optimize the existing urban rail transit network plan and develop a new one that aligns with the current development context. This will facilitate external regional integration, enhance internal quality and efficiency, support and guide the adjustment of the urban spatial structure, and promote the "second undertaking" and high-quality development of the Airport Economy Zone.

1 Development trends of urban rail transit network planning

Since the 18th National Congress of the CPC, the spatial layout of urbanization has been continuously optimized, with coordinated development of large, medium, and small cities, as well as small towns. Urbanization has entered a new phase focused on quality improvement and efficiency enhancement. Population and industries continue to concentrate on developed city clusters and their central cities, with industrial layouts being reshaped alongside the development of city clusters and metropolitan areas. Regional interconnected development has been continuously strengthened, and the scope of commuting travel has been expanding. The frequency of business, tourism, and other travel activities has also increased. Therefore, urban rail transit network planning must promote the "integration of four networks" [1]: trunk railways, intercity railways, urban (suburban) railways, and urban rail transit. The goal is to expand the service coverage of rail transit, optimize the urban spatial structure and functional layout, and ensure high-quality urban development.

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With the shift in China's urban development from large-scale incremental construction to a focus on quality improvement and structural adjustment of stock alongside incremental growth [2], urban rail transit development has entered a new phase. Unlike the previous focus on extensive growth in terms of scale and density, urban rail transit network planning now emphasizes functionality enhancement, service improvement, and optimization of existing systems. Planning methods now place greater emphasis on multi-level network integration and the quality and efficiency improvement of originally planned lines. The planning content also pays more attention to the coordination of production, living, and ecological elements across the entire region, as well as the alignment with the overall spatial structure and the "three zones and three lines" concept, which conforms to the ecological spatial pattern and the land protection requirements [3].

Against the backdrop of national spatial development, cities such as Beijing, Shenzhen, Zhengzhou, Changsha, Ningbo, Fuzhou, and Shenyang have successively undertaken revisions to their urban rail transit network plans. These revisions aim to develop a long-term blueprint for urban rail transit, construct a rail transit network that closely aligns with urban industrial development and spatial structure, support regional integration, promote key area development, facilitate the construction of "urban area on rails," and guide the orderly development of urban spaces.

As of December 2023, Zhengzhou has operated 10 urban rail transit lines with a total operational mileage of 277.7 km, ranking 13th in China. The annual passenger volume reached 62.534 million, with a passenger intensity of 7,500 passengers km^{-1} d^{-1} [4]. As one of the dual cores of Zhengzhou's urban functional space, the Airport Economy Zone has pioneered the completion of Metro Line 9 and the Zhengzhou-Xuchang urban rail transit line. This has further strengthened rail transit connections with Zhengzhou's main urban area and Xuchang City, efficiently integrating the Zone into the Zhengzhou metropolitan rail transit network and enhancing its radiation capacity.

2 Optimization ideas for the rail transit network in the Airport Economy Zone

2.1 Analysis of the adaptability of the existing urban rail transit network planning

The existing urban rail transit network planning adheres to the layout concept of "dense and efficient in the main urban area, networked connectivity within the Airport Economy Zone, rapid accessibility to key clusters, and interconnectivity within the metropolitan area." The planning includes eight urban rail transit lines in the Airport Economy Zone, with a total mileage of approximately 228 km (Fig. 1). However, the urban rail transit network planning does not consider the functional positioning and industrial layout of the newly expanded areas in the Airport Economy Zone. It exhibits weak connections with surrounding areas, including the Eastern New City and the expanded Economic Development Zone. The network layout is dense in the north and sparse in the south, with weak connections between clusters. Moreover, the transfer stations are excessively concentrated, resulting in significant pressure on hub transportation and reduced transfer efficiency. This planning fails to fully reflect the dual-core development model of Zhengzhou's central urban area.

To achieve a dual improvement in both spatial scale and standards for the Airport Economy Zone, it is essential to support the rail transit network with a broader vision, higher standards, and quality. Therefore, it is necessary to optimize the original rail transit network plan for the Airport Economy Zone and establish a rail transit system that aligns with the overall national spatial planning and the integrated transportation system planning, thereby promoting the high-quality development of the Airport Economy Zone.

Fig. 1 Existing rail transit network planning of the Airport Economy Zone

Data source: Zhengzhou Urban Rail Transit Network Planning (2020–2035)

2.2 Functional positioning

The population of the Airport Economy Zone is projected to reach 3.35 million by 2035. To meet this demand, it is essential to establish high-capacity rail transit as the backbone of the urban public transport system and develop a comprehensive public transport network primarily consisting of medium-capacity and multi-level ordinary-capacity buses and trams. Among these, high-capacity rail transit will mainly serve long-distance and inter-cluster travel, the medium-capacity system will focus on medium- and short-distance travel across clusters, and buses and trams will primarily serve short-distance and intra-cluster travel [5].

2.3 Development goals

2.3.1 Overall goal

With the overarching goal of constructing a new rail transit city characterized by "hub and gateway + industry and city integration," efforts should be accelerated to establish a multi-level, integrated rail transit network that aligns with regional integration and urban development. This will promote the compatibility of rail transit with urban space and foster synergistic symbiosis with land use, thereby supporting Zhengzhou in building an internationally efficient and highly connected open hub, ultimately enhancing its regional status.

2.3.2 Development indicators

In line with the new concept of building a people-oriented transport powerhouse, and in accordance with the development orientation of the Airport Economy Zone and the relevant planning requirements of the Standard for Urban Comprehensive Transport System Planning (GB/T 51328–2018), 15 development indicators (Table 1) have been established across five dimensions: regional integration, efficiency and convenience, green and low-carbon practices, people's livelihood services, and economic reliability.

2.4 Functional hierarchy

According to the Standard for Urban Rail Transit Network Planning (GB/T 50546–2018), the functional hierarchy of the urban rail transit network should be determined based on the characteristics of transport demand at different spatial levels and the service level requirements. The network should be composed of lines with different technical standards and system formats. Referring to the rail transit network functional system architecture of similar cities in China (Table 2), and based on the functional hierarchy of Zhengzhou's rail transit network, a three-tier and six-category rail transit functional hierarchy is proposed for the Airport Economy Zone. This hierarchy is designed to meet travel demands at different spatial scales (Fig. 2 and Table 3).

Table 1 Key indicator system of the planning and construction of rail transit in the Airport Economy Zone

Dimension	Development indicators	2035 indicator level
Regional integration	Travel time/h between the Airport Economy Zone and major Chinese cities	6
	Travel time/h between the Airport Economy Zone and major cities in the central plains urban clusters	2
	Travel time/h within the Zhengzhou Metropolitan Circle	1
	Travel time/h between the Airport Economy Zone and the main urban area and nearby regions	0.5
Efficiency and convenience	Average travel time/min on rail transit within the Airport Economy Zone	≤30
	Travel time/min for 95% of passengers during peak hours on a one-way trip within the rail transit system	≤45
	Travel time/min between each cluster and railway/aviation hubs by rail transit	≤30
	Average transfer time/min at both ends of a rail transit station	≤15
Green and low-carbon	Proportion of public transport in motorized travel during peak hours (%)	≥60
	Proportion of rail transit in public transport during peak hours (%)	≥60
	Proportion of rail transit in motorized travel in major corridors during peak hours (%)	≥60
People's livelihood services	Proportion of population and jobs covered within an 800 m radius of the rail transit station (%)	≥60
	Proportion of built-up land area covered within an 800 m radius of the rail transit station (%)	≥50
Economic reliability	Proportion of government capital in urban rail transit projects to the city's public fiscal revenue for the year (%)	≤5
	Proportion of TOD integrated development at rail transit stations (%)	≥70

2.5 Network optimization approach

Regional integration and the integration of industry and city is the booster for the high quality and rapid development of the Airport Economy Zone. The rail transit network adopts a comprehensive optimization strategy that emphasizes

Table 2 Functional hierarchy division in domestic and international urban rail transit systems

Region	Location	Area/km²	Population (per 10,000 people)	Functional positioning of public transport system	Transport mode share/%		Rail transit functional hierarchy
					Public transport share in motorized travel	Rail transit share in public transport	
Suzhou Industrial Park	Suzhou-Wuxi-Changzhou Metropolitan Area, Yangtze River Delta Urban Agglomerations, Suzhou Economic and Technological Development Zone	278	160	Integrated transportation system with rail transit as the core	65	60	Suburban railway Regional express line Subway
Yokohama City	Tokyo Metropolitan Area, designated as the sub-center of Tokyo, 33 km from downtown Tokyo	435	370	Public transport system with rail transit as the backbone and new types of transport as the mainstay	65	85	High-speed rail Urban (suburban) railway Urban regular speed railway
Shunde District	Guangzhou Metropolitan Area, Guangdong-Hong Kong-Macao Greater Bay Area Urban Cluster, designated as the sub-center of Foshan City, 30 km from Foshan city center	806	327	Public transport system with rail transit as the backbone, low-capacity public transport, and buses and trams as the mainstay	60 (2050)	60 (2050)	Regional express line Urban express line Regular speed subway

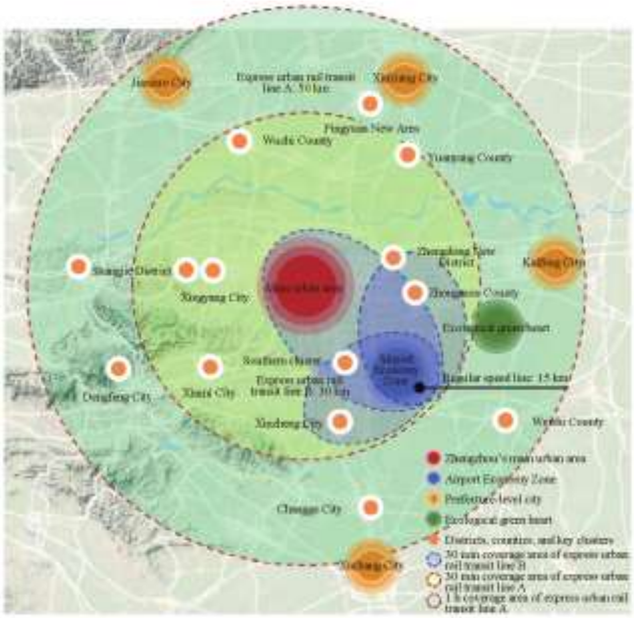

Fig. 2 Rail transit service area in the Airport Economy Zone

Table 3 Rail transit functional hierarchy division in the Airport Economy Zone

Service functions	Functional hierarchy	Service area	Service radius/km	Passenger flow characteristics	Speed target value/(km·h⁻¹)	Station spacing /km
Regional service	High-speed rail (trunk railway)	Achieve point-to-point connection with the central cities of major national urban clusters		Primarily business and leisure	≥250	≥30
	High-speed rail (regional intercity railway)	Nationwide and central plains urban cluster	≤200	Primarily business and leisure	≥200	20–30
	Express urban rail transit line A (urban railway)	Zhengzhou Metropolitan Circle	≤80	Various types, including commuting, business, and leisure	140–200	6–10
Urban service	Express urban rail transit line B	Nearby areas such as the main urban area and Xinzheng	≤30	Primarily commuting	120	3–5
Intra-area service	Urban rail transit regular speed line	Airport Economy Zone	≤15	Primarily commuting	80	0.8–1.5
	Low-capacity urban rail transit line	Within the Airport Economy Zone cluster	≤10	Primarily commuting	60–80	0.5–0.8

regional synergy, cluster integration, and service enhancement. It adheres to the principles of hierarchical optimization, prioritizing external connections before internal connections, and strengthening both external connectivity and internal system efficiency. This approach aims to fully leverage the pivotal role of transportation in urban development.

(1) The dual-core leadership of Zhengzhou's main urban area and the Airport Economy Zone is emphasized, and a multi-level rail transit network is established to achieve direct access, hub sharing, boundary integration, and network unity between Zhengzhou's main urban area and neighboring regional centers.

(2) Taking into account the new spatial pattern of "one core, six centers and six districts" in the Airport Economy Zone (Fig. 3), a rail transit network layout system in line with the newly expanded areas and the overall optimization and encryption of key areas is panned to promote intensive and high-quality development in key areas and support the integrated development of production and urbanization in the Airport Economy Zone.

(3) Based on traffic demands, the primary passenger flow corridors are optimized and densified, and a multi-level, integrated, and internally connected external rail transit network is built, guiding the city's transition towards intensive and high-quality development, promote the optimization of the transportation structure, and support the Airport Economy Zone in establishing a model for high-quality public transport development.

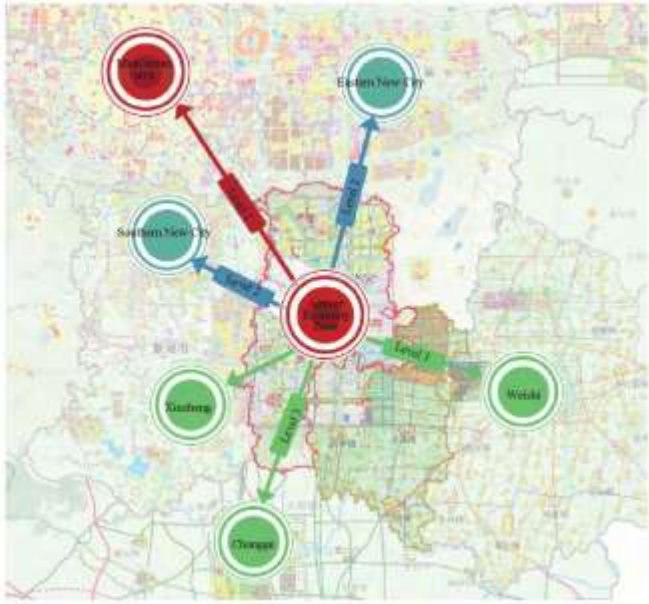

Fig. 3 External rail transit channels in the Airport Economy Zone

3 Rail transit optimization plan of the Airport Economy Zone

3.1 Network scale prediction

A variety of research methods, including the normative guideline method, traffic demand method, land use method, service level method, and construction feasibility method, are used to estimate the scale of the rail transit network. The reasonable scale for the rail transit network in the Airport Economy Zone is determined to be 180–210 km by 2035 and 240–270 km by 2050 (Table 4).

3.2 Traffic corridor analysis

The alignment of rail transit lines is closely related to actual passenger flow demand. To comply with the development of urban space and the growing demand for passenger flow, rail transit lines should be planned along the primary corridors of passenger flow, specifically in densely

Table 4 Forecasting methods of rail transit network scale in the Airport Economy Zone

Calculation method	Network scale/km		Method description
	Year 2050	Year 2035	
Normative guideline method	215	266	Using interpolation, the sum of population and employment density in 2035 and 2050 is expected to be 12,300 people per square kilometer and 15,800 people per square kilometer, respectively. The network density indicators are expected to be 0.638 km·km⁻² and 0.728 km·km⁻², respectively.
Traffic demand method	180–220	220–260	In 2035, the total motorized travel volume is expected to be 4.44 million person-time·d⁻¹, with a public transport mode share of 50%, and rail transit accounting for 50% of public transport travel. The rail transit transfer coefficient is expected to be 1.6, and the passenger intensity is expected to be 900–11000 person-time·km⁻¹·d⁻¹. In 2050, the total motorized travel volume is expected to be 5.20 million person-time·d⁻¹, with a public transport mode share of 60%, and rail transit accounting for 60% of public transport travel. The rail transit transfer coefficient is expected to be 1.5, and the passenger intensity is expected to be 12000–14000 person-time·km⁻¹·d⁻¹.
Land use method	190–200	260–270	In 2035 and 2050, the coverage rates of rail transit stations within an 800-meter radius are projected to be 40% and 50%, respectively. The overlap rates for these years are expected to be between 0.95 and 1.00 in 2035, and between 0.70 and 0.75 in 2050. Additionally, the station spacing is anticipated to range from 2.0 to 2.2 kilometers in 2035 and from 1.6 to 1.8 kilometers in 2050.
Service level method	190–230	230–260	In 2035 and 2050, the rail transit network length per million population is projected to be 65–70 km and 70–75 km, respectively.
Construction feasibility method	180–200	250–360	Based on existing rail transit lines, 7–9 km of new lines are constructed annually.
Comprehensive value	180–210	240–270	

populated and land-intensive areas in the primary travel directions (Fig. 4). The Airport Economy Zone overall forms two horizontal and three vertical primary traffic corridors. The peak passenger flow in the primary corridors ranges from 60,000 to 100,000 person-time h^{-1}, while the peak passenger flow in the secondary internal corridors ranges from 30,000 to 50,000 person-time d^{-1} (Fig. 5). Major passenger flow corridors should be served by high-capacity rail transit systems to form the main framework of the Airport Economy Zone's rail network, while also accommodating internal travel. Secondary passenger flow corridors should be served by medium to low-capacity rail transit systems to optimize the transportation structure.

3.3 Structural approach

Based on different levels of spatial structure and spatial scale, the rail transit network hierarchy and layout are planned to match these characteristics, forming a rail transit network that is coupled with the regional spatial structure and urban spatial structure to meet the diverse and varied transportation demands.

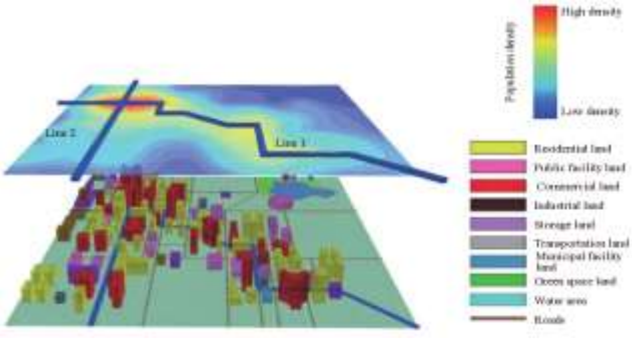

Fig. 4 The relationship between transportation corridors development and rail transit lines construction

Data source: Reference [6].

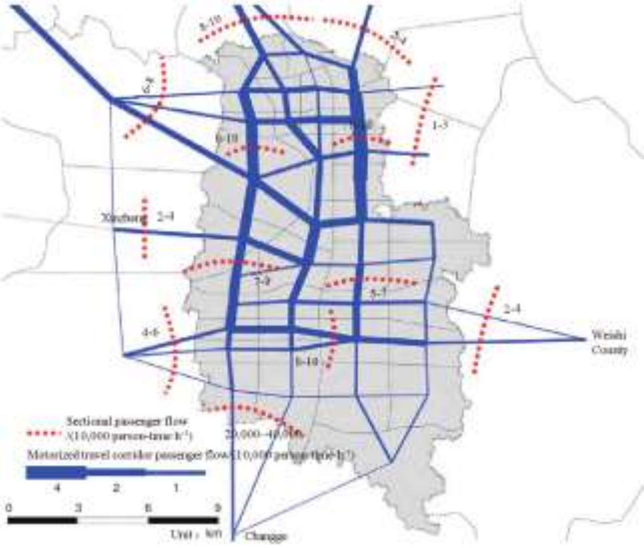

Fig. 5 Passenger flow corridors in the Airport Economy Zone

3.3.1 Layout of express urban rail transit line A

Centered around the dual cores of Zhengzhou's main urban area and the Airport Economy Zone, this layout focuses on the dual-core development linking the air and rail hubs. It forms a high-speed "loop" network that radiates and drives the high-speed development of the Airport Economy Zone, and enhances the service capabilities of the regional hub, so as to meet the rail transit travel service requirements of 30-min travel time and 60-min commuting (Fig. 6a).

3.3.2 Layout of express urban rail transit line B

Based on the regional spatial layout and traffic demand corridor distribution, this layout revolves around the dual development of the Zhengzhou International Convention and Exhibition Center and the Central China International Convention and Exhibition Center, forming a "loop + radiation" layout. Together with express urban rail transit line A, a network of high-speed rail and express rail transit is formed to meet the diverse and differentiated travel demands between the Airport Economy Zone and Zhengzhou's main urban area (Fig. 6b).

3.3.3 Layout of regular speed lines

In conjunction with the spatial distribution within the Airport Economy Zone and a detailed analysis of secondary passenger flow corridors, this layout further densifies the commuter rail transit network. It integrates the urban spatial structure and efficiently channels passenger flow into the express rail lines (Fig. 6c).

3.4 Optimization plan

3.4.1 Optimization plan for express urban rail transit line A

This line mainly serves the Zhengzhou Metropolitan Circle, and this plan strengthens the fast connection between the Airport Economy Zone and Zhengzhou's main urban area, improving commuting efficiency. The southern route of

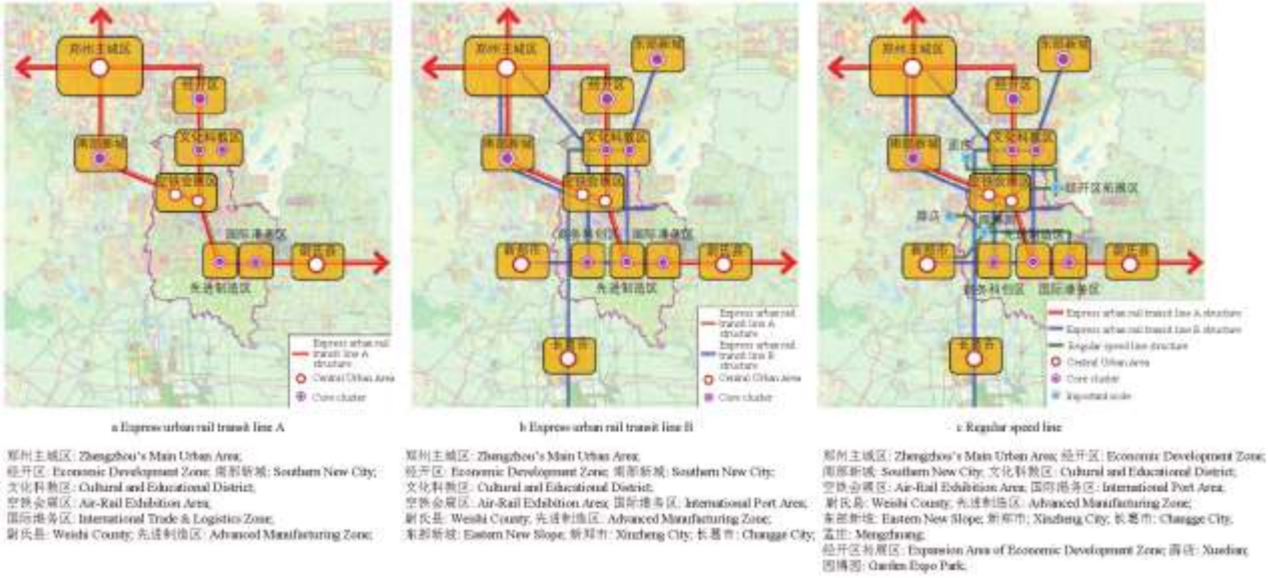

Fig. 6 Layout of rail transit lines with varied levels in the Airport Economy Zone

express Line K1 will be adjusted to the International Land Port core area, with provisions for extending it to the Weishi cluster. Such adjustment will enhance the radiation level of the rail transit hub to the surrounding clusters. The southern route of express Line K3 will be adjusted to the western side of the Shuanghe Lake Innovation District, strengthening the connection between the transit hub and key areas. After adjustments, the total length of express urban rail transit line A within the Airport Economy Zone will be 45.9 km.

3.4.2 Optimization plan for express urban rail transit line B

This line mainly serves commuting between the Airport Economy Zone and neighboring areas, as well as intra-cluster commuting. It covers the primary passenger flow corridors. A “loop + radiation” backbone network will be built with the Airport Economy Zone at the center, linking the peripheral sub-city. A total of five lines will be planned: Line 9, Line 11, Line 22, Line 25, and the Zhengxu Line, with a total length of 156.1 km.

3.4.3 Optimization plan for regular speed lines

Regular lines serve the passenger corridors within key areas of the Airport Economy Zone and its neighboring clusters, providing rail transport services both internally and between adjacent clusters, while efficiently channeling passenger flows to the express rail lines. Taking into account the internal spatial structure and land layout of the Airport Economy Zone, three regular speed lines are planned, including Line 21, Line 23, and Line 27, totaling 72.8 km.

The optimization plan of the rail transit network for the Airport Economy Zone is shown in Figure 7. The overall passenger flow in the network is relatively balanced. During peak hours, the unidirectional passenger flow in the Airport Economy Zone is 15,000–20,000 person-time·h^{-1}. The coverage of the station within an 800 m radius includes 2,319,000 people and 948,000 employment positions, with coverage rates of 69.2% and 55.7% for population and employment, respectively. The passenger flow intensity reaches 12,400 person-time·km^{-1}·d^{-1}, with a transfer coefficient of 1.53. The share of rail transit in public transport travel is 61% (Fig. 8).

Fig. 7 Optimization plan for rail transit network in the Airport Economy Zone

3.5 Comparison with the existing planning scheme

The rail transit network optimization plan for the Airport Economy Zone is designed from the perspective of the dual-core approach, focusing on the main urban area and the

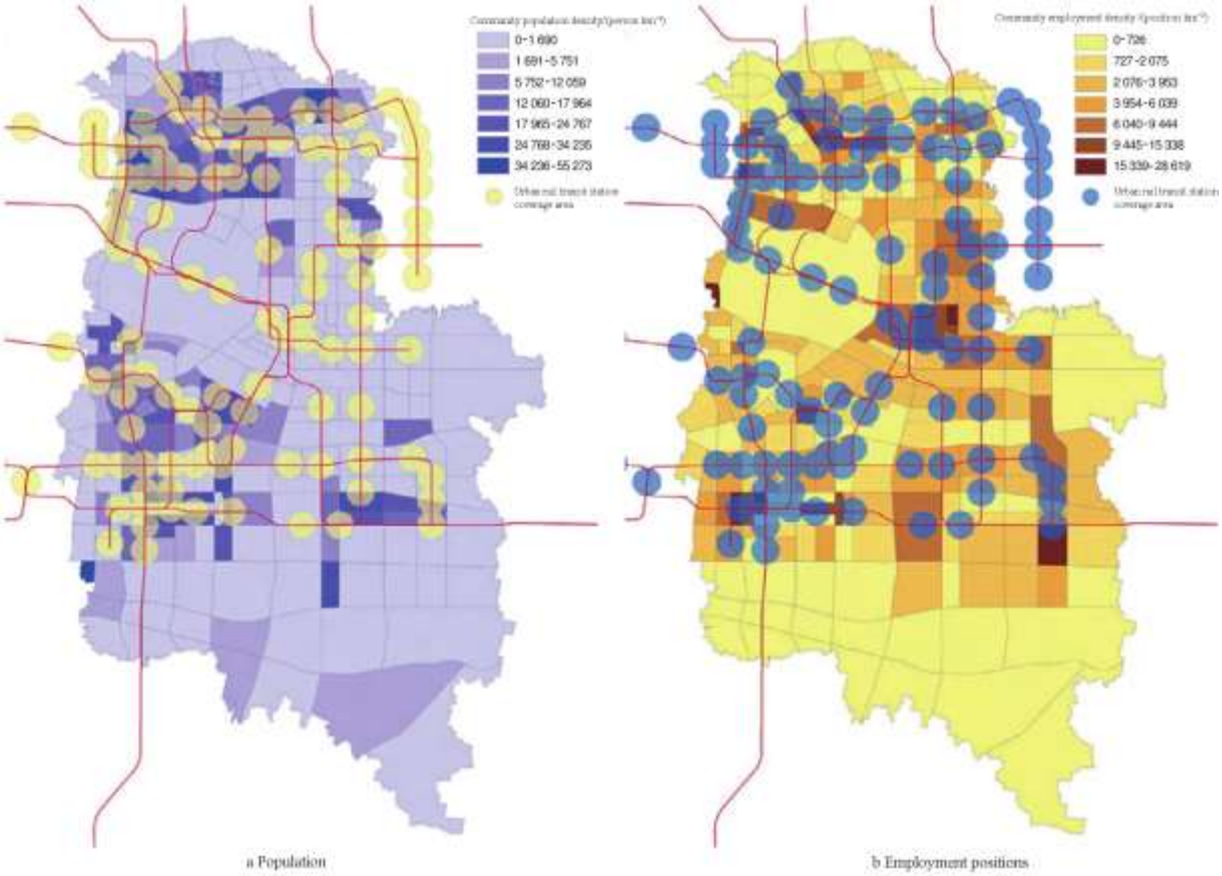

Fig. 8 Population and employment positions covered within the 800 m range of rail transit stations

Airport Economy Zone. The plan strengthens external connections while considering the integration of industry and city, as well as hub services. After optimization, the total length of the rail transit network increases by approximately 46.8 km, with a line overlap ratio of about 70%, making it more aligned with the development needs of the Airport Economy Zone. The number of transfer stations increases from 23 to 36. Commuting between districts or hubs can now be achieved either directly or with one single transfer. The total number of transfers required between district centers or hubs decreases from 21 to 7. The Hangkonggang Station now provides direct connectivity to major districts, significantly enhancing the accessibility of the rail transit network and offering greater travel convenience to residents.

3.6 Line operation organization

A reasonable and feasible line operation organization helps improve the transportation capacity and the operational efficiency of vehicles. Urban rail transit systems commonly employ three operational organization modes: multi-route mixed operation, long and short routing, and single-route operation. For lines exceeding 80 km in length with unbalanced passenger flow distribution, serving metropolitan areas, and characterized by significant peak passenger flow in the central urban area but lower flows at both ends, the nested or multi-route mixed operation mode is recommended. For lines longer than 40 km, with uneven passenger flow distribution, serving urban areas and surrounding towns, and featuring significant peak passenger flow at one end of the line, the long and short routing mode is recommended. For lines between 15 km and 35 km, with relatively balanced passenger flow distribution, serving internal areas of the Airport Economy Zone, the single-route operation mode is recommended.

Therefore, as for the express urban rail transit line A in the Airport Economy Zone, the multi-route mixed operation mode is recommended; for the express urban rail transit line B, the long and short routing mode is recommended; for the regular speed lines, the single-route operation mode is recommended.

4 Conclusions

Based on inheriting the original network framework and the unchanged external terminals, the optimized rail transit network plan for the Airport Economy Zone is based on its development demands and fully connected with the new round of territorial spatial planning, focusing on the four aspects of dual-core leadership, dual-exhibition, dual-hub coordinated development, strengthening external radiation and improving internal connections, and forming a "link-and-radiation" rail transit layout. The optimized rail transit network consists of 10 lines with a total scale of 274.8 km, connecting important nodes and cluster centers, covering primary and secondary passenger corridors, and supporting the formation of the urban spatial structure, which is of great significance to the construction of the "Airport Economy Zone on Rails" and the promotion of high-quality and sustained development of the city.

The next step should be to improve the supporting facilities around rail transit stations. Based on passenger flow and location, facilities such as parking and transfer stations, bus terminals, and non-motorized vehicle parking should be reasonably arranged to expand the service range of rail transit. Additionally, the bus routes along the rail transit lines should be optimized, the competing routes should be reduced, the commuting lines should be increased, and circular lines should be introduced to feed passenger flow to the rail system through a multi-level bus and tram network. Furthermore, TOD (Transit-Oriented Development) should be promoted around rail stations, optimizing land use and forming a land development pattern based on rail transit as the axis, so as to increase the population and employment positions directly served by rail transit, and give full play to the backbone and leading role of rail transit.

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