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Development Demand, Connotation and Path of Four-Network Integration of Rail Transit: A Case Study of Yangtze River Delta City Cluster

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Abstract: In China, the railway passenger flow in major city clusters and metropolitan areas has changed from long-distance, low-frequency, and low-time value to medium-and short-distance, high-frequency, and high-time value. Through a comparison of development experiences of advanced regions in the world, this paper identifies the structural limitations in the layout of regional rail transit network in China's city clusters. Understanding the four-network integration development will enhance the structure optimization of intercity transportation. Based on the review of urban space and inter-city passenger flow in the Yangtze River Delta, the paper proposes a whole-process travel to serve as the development connotation and identifies the development focus and path of the four-network integration. At the network level, priorities are given to the connection, shared channel, and coordinated operation of intercity railways and municipal (suburban) railways within metropolitan areas and municipal regions. At the terminal level, key focuses include the enhancement of multi-point layout, connection with urban rail transit, and station-city integration that feature low-carbon and efficient green distribution modes. Finally, the paper concludes that the development mechanism of four-network integration should shift from national authority to local guidance. Further exploration and innovation are needed in enterprise operation, cross-regional collaboration, and operational service cooperation. **DOI:** 10.13813/j.cn11-5141/u.2022.0503-en

Keywords: rail transit; four-network integration; railway terminals; intercity railways; municipal (suburban) railways; Yangtze River Delta

0 Introduction

Since the 21st century, with China's urbanization and rapid economic and social development, the railway system has entered a period of rapid development. By the end of 2021, the operating mileage of China's railways has reached 150 000 km, of which the operating mileage of high-speed rails (hereinafter referred to as HSRs) has exceeded 40 000 km [1], accounting for more than two-thirds of the operating mileage of the world's HSRs. In the past 10 years, the construction of HSRs has greatly changed the process of regional and urban development and largely met people's requirements for convenient travel. In the next 10 years, driven by the integration of city clusters, high-quality development of metropolitan areas, and new infrastructure, a multi-level rail transit network will be gradually formed, which will further enrich and deepen the reform of rail transit and city development.

In February 2019, the *Guideline of National Development and Reform Commission on Cultivating and Developing Modern Metropolitan Areas* (Development and Reform Planning [2019] No. 328) proposed to promote the integration of four networks including trunk railways, intercity railways, municipal (suburban) railways, and urban rail transit [2]. In December 2019, the Central Committee of the Communist Party of China and the State Council issued the *Outline of the Integrated Regional Development of the Yangtze River Delta*, which proposed to jointly build the Yangtze River Delta on the rail and accelerate the construction of a modern rail transit system that integrates HSRs, normal-speed railways, intercity railways, municipal (suburban) railways, and urban rail transit [3]. The Yangtze River Delta is the region with the highest degree of urbanization, the most densely distributed cities, and the highest level of economic development in China. At the end of the 13th Five-Year Plan, the operating mileage of railways exceeded 12 800 km, and the operating mileage of HSRs exceeded 6 000 km. The urban integration effect of cities in the Yangtze River Delta has continued to expand, and all prefecture-level

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cities in the region except Zhoushan have operated high-speed trains.

As city clusters and metropolitan areas continuously develop, the demand for intercity transportation across administrative regions is growing rapidly, and it presents obvious spatial differentiation. The intercity transportation system represented by rail transit has great advantages in building an efficient and convenient intercity transportation system and supporting the spatial organization of city clusters by virtue of its punctual, reliable, economical, and fast characteristics [4–5]. Therefore, accelerating the four-network integration of rail transit to further exert the backbone role of rail transit in a comprehensive transportation system is not only an important step for promoting the low-carbon development of intercity transportation but also an important support for regional integration development. In this context, this paper takes the Yangtze River Delta as an example to analyze the development demand, connotation, and path of four-network integration and proposes a new development mechanism for four-network integration.

1 Trend of railway supply and demand in China's city clusters

1.1 Railway passenger flow characteristics

China's urbanization level has increased from 36.1% in 2000 to 63.9% in 2020, undergoing 20 years of rapid growth. The three major city clusters represented by the Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta have become important regional units that support national economic growth, promote coordinated regional development, and participate in the global division of labor and competition. As China's economy enters a new stage of development, city clusters begin to integrate, and regional central cities play an important role in radiating and leading surrounding areas. The integrated development pattern is becoming more and more prominent, and regional space-time relationships are thus reshaped. Under closer urban connections, the efficiency of infrastructure networks represented by railways has been continuously improved, which not only expands the space-time scope of urban resource allocation and personnel flow but also promotes new intercity transportation needs such as intercity business, leisure, and commuting.

The trend of railway travel in the three city clusters shifts from long-distance, low frequency, and low-time value to short- and medium-distance, high frequency, and high-time value, which is the most important characteristic. From 2010 to 2019, the average railway travel distance of the whole country and the three city clusters continued to decline, of which the travel distance of the Yangtze River Delta and Guangdong Province (Pearl River Delta) was significantly lower than that of the Beijing-Tianjin-Hebei region (Fig. 1), which reflected the increasing dependence of medium- and short-distance intercity transportation on the railway system under the strong connection of regional economies. At the same time, the average number of railway trips in the three city clusters was steadily increasing, and the level of trips was significantly higher than the national average (Fig. 2). According to this trend, the number of railway trips in major urban-intensive areas will maintain rapid growth for a long time. It is estimated that by 2035, the number of railway trips in the Yangtze River Delta and Pearl River Delta will reach 15–20 times·person^{-1}·a^{-1}.

Corresponding to the passenger flow characteristics of medium- and short-distance and high frequency, the scale of high-time value travel represented by business and commuting in city clusters is increasing. According to the survey of Beijing-Tianjin intercity railway travel [6], the passenger flow of Beijing-Tianjin intercity travel for business and commuting accounted for nearly 55% in 2017, and this proportion is still increasing. In terms of business trips, Wang [7] found through a survey that business trips (including government business trips) were the most important mode for HSR travel in the Yangtze River Delta. In terms of intercity commuting, according to statistics and surveys, there are

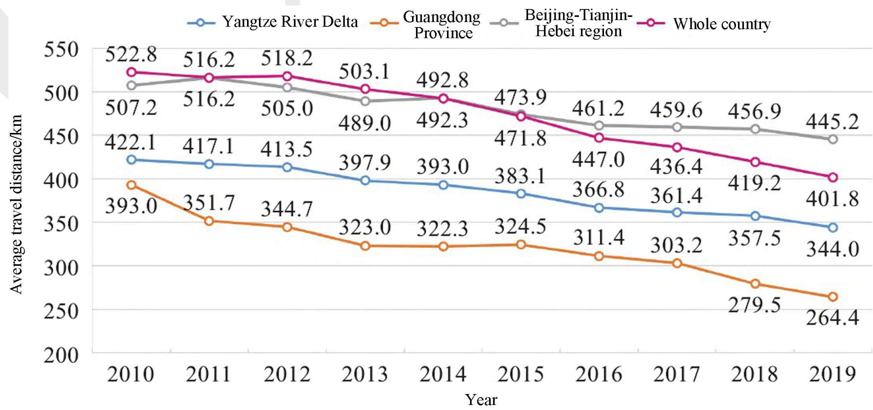


Fig. 1 Changes in average railway travel distance in three major city clusters from 2010 to 2019

Data source: statistical yearbooks of the whole country and relevant cities.

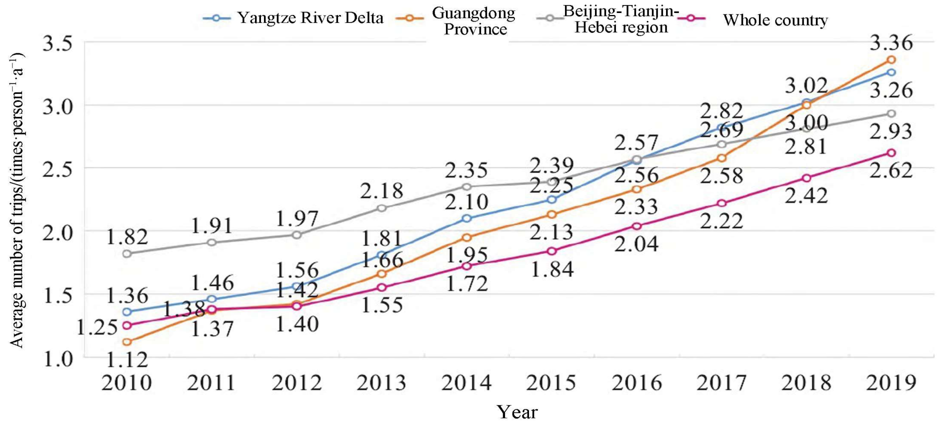


Fig. 2 Changes in average number of railway trips in three major city clusters from 2010 to 2019

Data source: statistical yearbooks of the whole country and relevant cities.

about 72 000 intercity commuters in Shanghai every day, with the largest share of Shanghai-Suzhou commuting [8]; the average daily commuters between Guangzhou and Foshan reaches 340 000, with an obvious two-way commuting feature [9]; the total number of intercity commuters between Beijing and Tianjin is 37 000 per day with a commuting frequency of 3.57 times·person^{-1}·week^{-1}, and the commuting group shows the working and living state of one round trip a day [10]. Generally speaking, business travelers and commuters have become an important source of passengers for railways. These people are more sensitive to time, prefer "direct arrival at destination", and have a higher demand for high-quality facilities around railway stations.

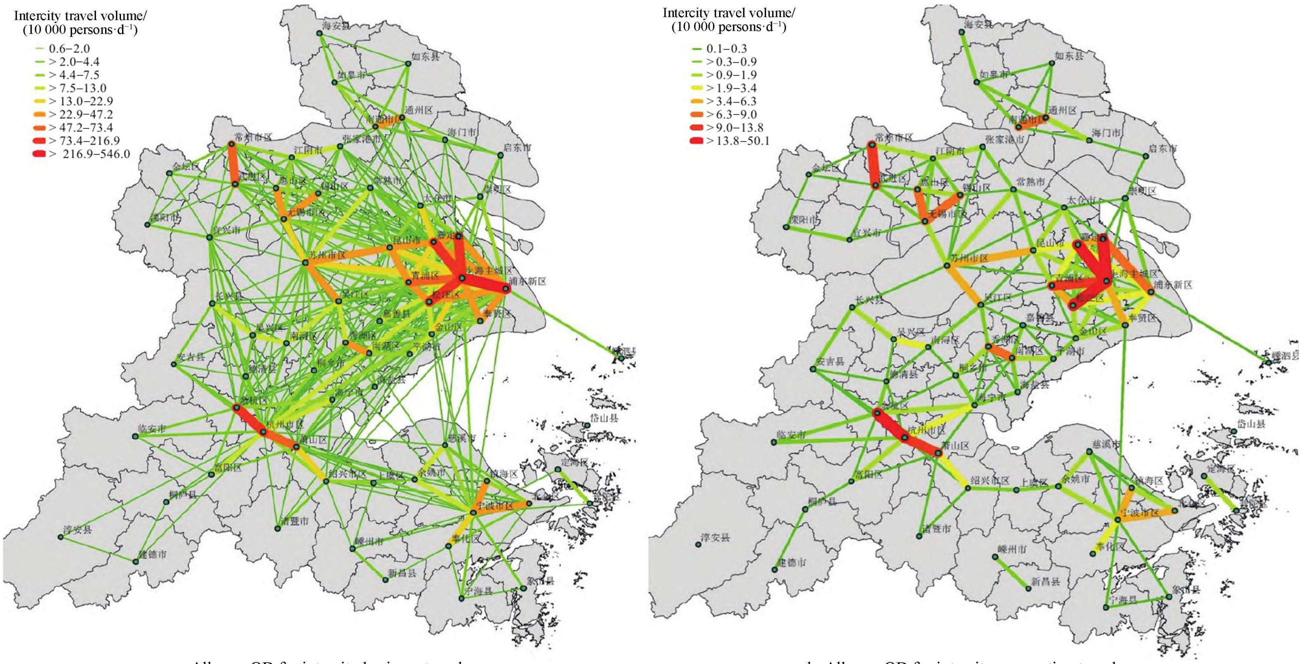
1.2 Intercity travel characteristics in metropolitan areas

The changes in the railway passenger flow characteristics reflect the changes in the intercity travel characteristics of city clusters, especially metropolitan areas. As China's economy enters a stage of high-quality development, a structural system with richer layers and closer relationships has formed within the city clusters, that is, the spatial form of the metropolitan area. A metropolitan area is a geographical spatial form with a super (extra) large city or a large city with strong radiation driving functions as the center and a one-hour traffic circle as the basic scope. Compared with those of city clusters, the intercity travel characteristics of metropolitan areas are more representative and manifested by the continuously expanding scale of intercity business travel within the metropolitan area and the stronger demand for the convenience of railways.

Within the overlapped scope of the Shanghai metropolitan area and Hangzhou metropolitan area, urban areas and counties are used as research units to analyze the characteristics of intercity travel in the metropolitan area (Fig. 3). The results show that the average daily business travelers across administrative units within this scope reach 30.7 million, with the average travel distance of 37.8 km, and the average daily commuters across administrative units are 3.46 million, with the average travel distance of 25.6 km.

In a space similar to metropolitan areas, the scale of travel across administrative units is increasing. In addition, most travelers and commuters go directly to the city or cluster center and have higher travel requirements for reliability, direct accessibility, and convenience, and they are sensitive to travel time consumption and urgently require less time loss during transfer and connection. This kind of travel is between daily travel within the city and long-distance travel outside the city. Due to urban traffic jams and driving restriction measures, it is difficult to rely on private motorized transportation to complete intercity travel and ensure timeliness through the urban transportation system, but this problem falls into the advantageous service area of intercity railways and municipal (suburban) railways.

However, for a long period of time in the past, the transportation development mode of city clusters and metropolitan areas was still dominated by the construction of highways and expressways, and the railway network density was significantly lower than that of highways in most areas. Especially in the Yangtze River Delta region, where the economy is relatively developed, and the development is relatively balanced, the expressway network density has remained relatively high, while the increase in the railway network density has shown a slowing trend in recent years, which makes the gap between the two networks more obvious. In contrast, in other regions and countries such as Europe and Japan, etc., the density of the railway network is generally higher than that of the expressway, and the operation service has reached the level of public transportation. This difference in the supply of transportation facilities essentially reflects the development orientation of intercity transportation. As more intercity travel shifts to intercity business, commuting, etc., the scale of relevant groups is increasing. Railways will play an increasingly important role by virtue of their reliable, fast, and economical characteristics and be more competitive and attractive in satisfying passengers' high time-value sensitivity.



a All-way OD for intercity business travel b All-way OD for intercity commuting travel

Fig. 3 Intercity travel characteristics in Shanghai metropolitan area and Hangzhou metropolitan area

Data source: the data platform of the Shanghai Branch of China Academy of Urban Planning and Design.

2 Integration requirements of regional rail transit network from the perspective of international comparison

The socio-economic backgrounds, technical standards, and institutional mechanisms of railway development in countries are different, and it is difficult to make sweeping generalizations. Selecting countries or regions that are similar to China's major city clusters in terms of geographical scale, population size, and economic level and comparing them in terms of railway network structure and passenger flow level will help people grasp and review the future development direction of regional rail transit.

In some European countries with a scale similar to that of the Yangtze River Delta, the average railway travel distance is shorter, the number of trips is higher, and the passenger volume has reached a higher level. For example, in France, Spain, and Germany, the average railway travel distance is only 46–70 km, and the average number of trips reaches 12–25 times·person^{-1}·a^{-1}; thanks to the well-developed private railway network, railways have become an important mode of daily commuting in Japan, with an average travel distance of only 28.9 km and an average number of trips of 74.3 times·person^{-1}·a^{-1}. Railways are an important part of the daily life and travel of residents in developed countries such as Europe and Japan. In contrast, in China's three major city clusters, railways are still used as a means of urban external transportation, and the service distance is relatively long, with an average travel distance of 300–400 km and an average number of trips of less than 3 times·person^{-1}·a^{-1}, which is much lower than that in developed countries (Table 1). Due to the vast territory and wide range of transportation connections, there are still large differences in the travel distance and the number of trips in similar city clusters in China.

From the experience of developed countries, it can be seen that a shorter travel distance and higher average number of trips can lead to an order-of-magnitude increase in railway passenger flow and truly make railways become a low-carbon and efficient travel mode in city clusters. At present, Shanghai-Hangzhou, Shanghai-Suzhou, Beijing-Tianjin, Guangzhou-Shenzhen, and similar city pairs have already been advantageous railway service intervals. For example, trains departing from Shanghai Station and arriving at Suzhou, Wuxi, and Hangzhou account for 15%–20% of total daily trains, and Shanghai Hongqiao Station has about 5% of total daily trains dedicated to the Shanghai-Hangzhou section. These medium- and short-distance and high-frequency trains have strengthened the railway transport capacity for local intervals in urban-intensive areas and effectively increased the passenger volume of railways, which will become one of the important trends in future railway development.

The density of the HSR (with a speed exceeding 250 km·h^{-1}) network in China's three major city clusters generally exceeds that in Europe and Japan. For example, the density of the HSR network in the Yangtze River Delta is 1.6–2.3 times that in Germany and Japan (Table 2). Since HSRs in China are more responsible for inter-regional high-speed connections in the vast territory, a higher-density HSR network is appropriate and necessary. However, compared with that in

Europe and Japan, the railway network density of the three major city clusters is still far behind, only 25%–60% of that in Germany and Japan. Therefore, in terms of the closer connections within city clusters and metropolitan areas, it will be difficult to realize the effective service for medium- and short-distance and high-frequency travel if there is no higher-density railway network coverage (especially intercity railways and municipal (suburban) railways).

Constructing city clusters and metropolitan areas on the rail has become an important strategy and step for China to promote the development of regional integration, and attention should be paid to the changes in the characteristics of passenger flow groups at different levels, especially to the rapid growth of medium- and short-distance intercity passenger flows and their urgent requirements for timeliness and convenience. The scale of HSRs and urban rail transit in China's major city clusters has been relatively developed, while regional rail transit at the intermediate level is relatively lagging, which is difficult to serve intercity travel groups with medium- and short-distance, high-frequency, and high-time value requirements both in terms of facility scale and service mode. Therefore, in the future, we should make up for shortcomings according to local conditions, coordinate the development of the four-network integration, and explore the "one network" of rail transit operation and management, so as to further promote the development of regional integration and optimize the regional transportation structure.

Table 1 Comparison of national and regional railway travel characteristics in 2018

Country or region	Population/ 10 000 persons	Railway passenger volume/(10 000 persons·a^{-1})	Passenger turnover volume/100 million persons-km	Average travel distance/km	Railway average number of trips/ (times·person^{-1}·a^{-1})
China	139 010	308 379	13 456.92	436.4	2.22
Yangtze River Delta	21 600	63 004	2 276.83	361.4	2.82
Beijing-Tianjin-Hebei region	11 280	30 250	1 390.38	459.6	2.69
Guangdong Province	9 440	28 766	872.08	303.2	2.58
France	6 700	127 147	878	69.1	18.98
Spain	4 650	57 242	267	46.6	12.31
Germany	8 250	207 564	958	46.2	25.16
Japan	12 610	937 189	2 706	28.9	74.32

Data source: statistical yearbook data and public information of relevant countries or regions.

Table 2 Comparison of national and regional railway development characteristics in 2018

Country or region	Area/ 10 000 km^2	Permanent resident population/ 10 000 persons	Population density/ (person·km^{-2})	HSR mileage/km	HSR network density/ (km·10 000 km^{-2})	Railway operating mileage/km	Railway network density/ (km·10 000 km^{-2})
China	960	139 010	144.8	25 164	26.2	126 970	132
Yangtze River Delta	35.83	21 600	602.8	3 844	107.3	10 097.9	282
Beijing-Tianjin-Hebei region	21.72	11 280	519.3	1 678	77.3	9 575	441
Guangdong Province	17.97	9 440	525.3	1 542	85.8	4 201	234
France	63.31	6 700	105.8	2 734	43.2	28 364	448
Spain	50.60	4 650	91.9	2 471	48.8	15 922	315
Italy	30.13	6 060	201.1	896	29.7	17 906	594
Germany	35.71	8 250	231.0	1 658	46.4	38 990	1 092
Japan	37.80	12 610	333.6	2 559.8	67.7	16 976.4	449

3 Demand orientation and connotation analysis of four-network integration in the Yangtze River Delta city cluster

3.1 Demand orientation of intercity transportation in the Yangtze River Delta

Relying on the highly developed urban economic and industrial network and the ever-expanding traffic corridors, the demand for intercity transportation in the Yangtze River Delta city cluster tends to develop in three directions. 1) A more balanced and networked demand trend. In addition to the continuously improved radiation power of the central city, the urban-intensive areas represented by the Suzhou-Wuxi-Changzhou metropolitan area show obvious clustering in terms of urban space, and the intercity connections have obvious characteristics of equalization and decentralization. Especially under the combined effect of the municipal transportation network and the city's adjacent areas, the characteristics of equalization and networking will be further strengthened. 2) Demand for direct access to the city center. Business travel is the main purpose of intercity travel in this region. With the emergence of high-frequency intercity passenger flow groups, direct access to the city center has become an urgent need. These groups have clear travel intentions and travel destinations and prefer to travel directly to and from the city center with agglomerated functions and reduce unnecessary transfer and connections. 3) The convenience requirement of "direct arrival at the destination". As railway terminals and functions of surrounding cities improve, the choice of travel destinations for intercity passenger groups is often the station-city area, so as to avoid the time consumption of entering the urban area and complete tasks such as business, meeting, shopping, etc. around the railway terminal. Therefore, clear, smooth, and fast traffic lines and a more perfect and high-quality station-city environment are required.

These new demands and new features of intercity travel undoubtedly make the reliability and timeliness of travel prominent. Reducing travel time consumption in the whole process has become the core appeal of most travelers. For high-frequency and regular intercity passenger flow groups, the increase in the train speed, the public transportation used in the transit and transfer process, and the compression of the stay time in the station are all important demands to reduce the travel time consumption in the whole process. At the same time, the process of entering and exiting the station, mutual trust in security checks, and seamless integration of both ends are also important aspects that affect travel efficiency.

3.2 Analysis of intercity transportation shortcomings in the Yangtze River Delta

The shortcomings on the transportation supply side that serve the rapidly growing demand for intercity travel are obvious. In the past few years, railway construction has focused on constructing HSRs to serve the connection of national trunk corridors and has made great progress. However, intercity transportation in the Yangtze River Delta has insufficient consideration for the construction of an intercity rail transit network that can cross administrative regions and enable public transportation operations, the integration of railway terminals and urban spaces, and the coordinated division of labor of railway terminals. These problems are mainly reflected in the following aspects: 1) the intercity railway network is small in scale and low in coverage. With Shanghai metropolitan area as an example, the total mileage of the rail transit network serving cross-regional intercity travel in 2019 was 2 070 km, which is still far behind the scale of 4 260 km in the Tokyo metropolitan area. Although most normal-speed railways have obvious advantages of lines and locations, and the main stations are closely integrated with urban areas, intercity trains have not been operated, and the advantages of railway transportation fail to be fully utilized [11]. The total mileage of the intercity railway network in the Shanghai metropolitan area is only 520 km, and a large number of corridors are not covered. Furthermore, the design standards of different lines are different, and the structural shortcomings are very obvious. 2) The railway terminals are far away from the center, and it is difficult to ensure direct access to important node areas. In Shanghai metropolitan area, many important node areas still lack railway terminals, and the access ratio of railway terminals in key functional areas is only about 1/3. At the same time, many newly-built railway terminals are far away from the city center, which results in low direct accessibility of rail transit travel. For example, the distance between city centers such as Jiaxing and Huzhou and their railway terminals is 7–10 km.

3.3 Connotation of four-network integration

Conceptually speaking, the four-network integration is to realize the network integration of HSRs, intercity railways, municipal (suburban) railways, and urban rail transit and systematically build a "one network" pattern. From the starting point and essence of the four-network integration, it is to realize a more convenient flow of people in the region, focus on the whole process of intercity travel of travelers, and use multi-level rail transit resources to meet the diverse travel needs of various passenger groups. In turn, this process can further promote intercity personnel exchanges and improve the efficiency of integrated allocation of space resources and functions.

The four-network integration is by no means a simple superposition of networks and integration of railway terminals. Instead, it should take the needs of travelers as the core orientation to provide efficient, convenient, reliable, multi-level, and integrated rail transit services, fully meet the complex and differentiated needs of diverse passenger groups, and support the high-quality development of city clusters and metropolitan areas. Specifically, the four-network integration should pay attention to the differentiated needs of different passenger groups and realize the direct connection between the place of departure and destination as much as possible. This requires that the line corridors should be connected on the premise of meeting the demands, so as to make it possible to operate trains based on the point-to-point demand; attention should be paid to the demand of "direct arrival at the destination" to realize the efficient link and integration of multi-level railway terminals and urban spaces; innovative integration of operation management, ticketing system, etc., should be promoted and integrated into planning and construction for consideration, so as to provide high-quality and integrated rail transit services. Therefore, the four-network integration is not only the integration of networks and terminal facilities but also the integration of transportation and space functions, as well as the integration of operation services.

Suzhou's four-network integration plan serves as an example and proposes that Suzhou will be committed to building a rail transit system of "four-network integration and one-ticket for city traveling" (Fig. 4), whose core concept is to realize the two-network integration and combined system of intercity railways and municipal (suburban) railways, so as to jointly promote the integration and coordination of metropolitan areas and support the integrated development of municipal areas. In terms of integration strategy, Suzhou will highlight the integration of functions to provide demand and service-oriented differentiated rail transit services and that of space to strengthen the support of corridors and promote the integration of regions and municipal areas. In addition, it will emphasize the integration of terminals to create an efficient and convenient "zero transfer" system of railway terminals and the timing coordination to better leverage the advantages of rail transit network operation and organization.

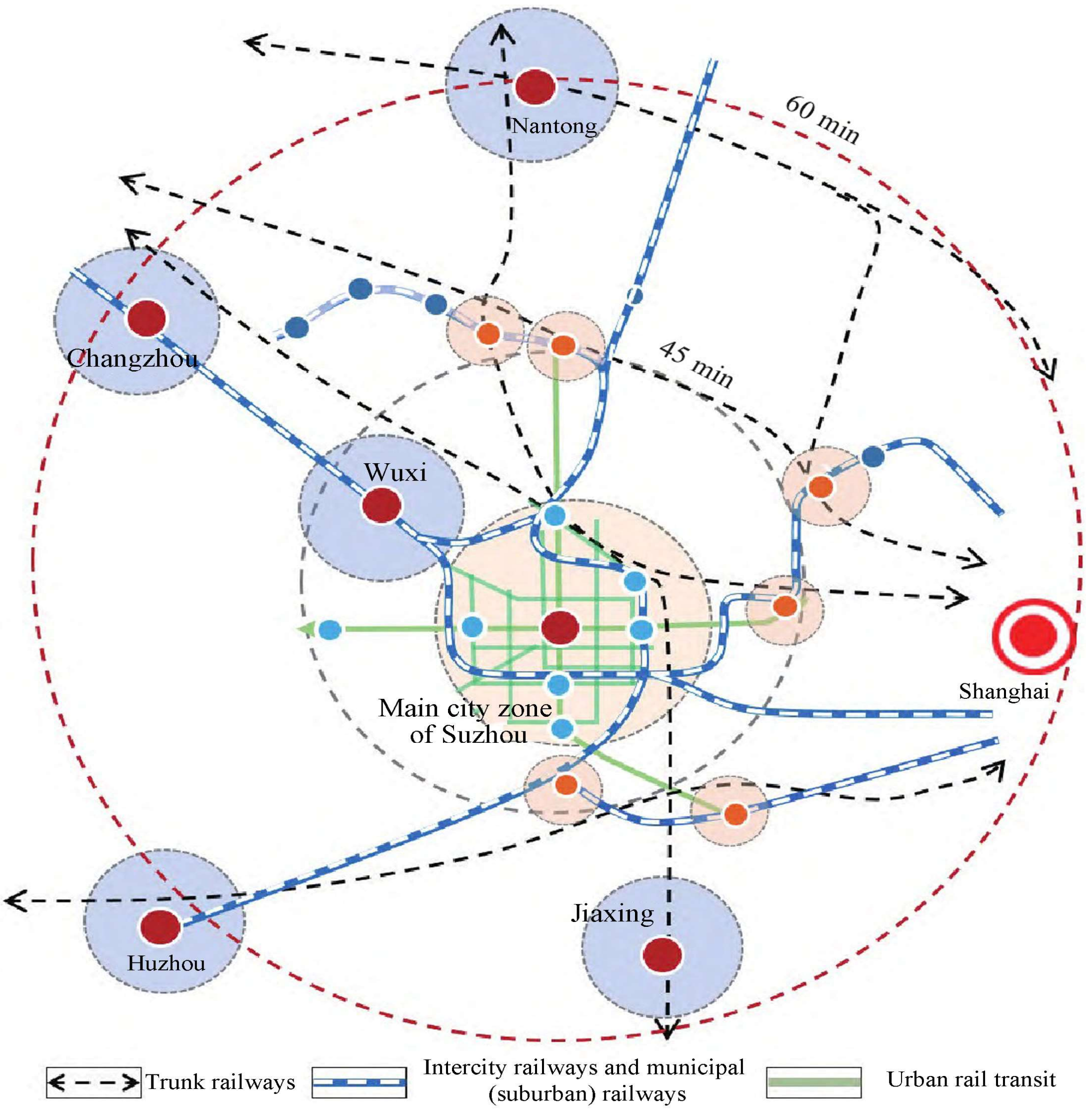


Fig. 4 Conceptual diagram of four-network integration of Suzhou

4　Development paths of four-network integration in the Yangtze River Delta city cluster

4.1　Overall strategy: from HSR corridor to multi-level complete network

The focus of the four-network integration in the Yangtze River Delta is to realize the "corridor-network" development. In view of the analysis of the current situation, facilities under construction, and planning, the corridors of the Yangtze River Delta HSR (350 km·h^{-1}) will present a pattern featuring six vertical high-speed railways and five horizontal high-speed railways in the future (Fig. 5), with a total scale of more than 6 000 km. If built on this scale, the HSR network can fully support the high-speed connections between city clusters and central cities in the Yangtze River Delta and adapt to a large-scale national spatial scale and multi-center pattern. But it is not enough to rely solely on the HSR network. In the future, the Yangtze River Delta city cluster should make up for the structural shortcomings of rail transit and focus on constructing an intercity rail transit network for metropolitan areas, which has a target speed of 120–200 km·h^{-1} and access to the city center or the cluster core.

4.2　Path 1: advocation of two-network integration of intercity railways and municipal (suburban) railways

According to the actual situation of the Yangtze River Delta, the four-network integration focuses on promoting the two-network integration and direct connection of intercity railways and municipal (suburban) railways, so as to further adapt to the medium- and short-distance passenger transport demand and reflect the passenger flow characteristics in urban-intensive areas. In this process, the realization of urban rail operation and public service of the railway system is also an important development direction.

The technical advantages of intercity railways and municipal (suburban) railways lie in their ability to adapt to and support the trend and requirement of the integration and high-quality development of city clusters. On the one hand, the multi-pattern scheme has both high timeliness and high accessibility. The design speed can meet the goal of traveling 60–100 km within one hour, and important functional nodes of the city can be reached to support the urban integration of metropolitan areas. On the other hand, multi-pattern selection improves adaptability and compatibility. It strengthens the utilization of existing railway resources, such as the reconstruction of the Shanghai-Jinshan railway, with a total length of 56.4 km and nine stations, which realizes the rapid connection between the suburbs of Jinshan and the central city of Shanghai.

4.2.1　Top-down: connections between municipal functional areas undertaken by intercity railways in metropolitan areas

The planning and construction of intercity railways are generally initiated and coordinated at the provincial level. In the urban-intensive areas of the Yangtze River Delta, the functions of intercity railways should be downward to connect the core areas of the city, important urban areas, and municipal functional nodes and couple the line and network layout and the destinations of intercity passenger flow.

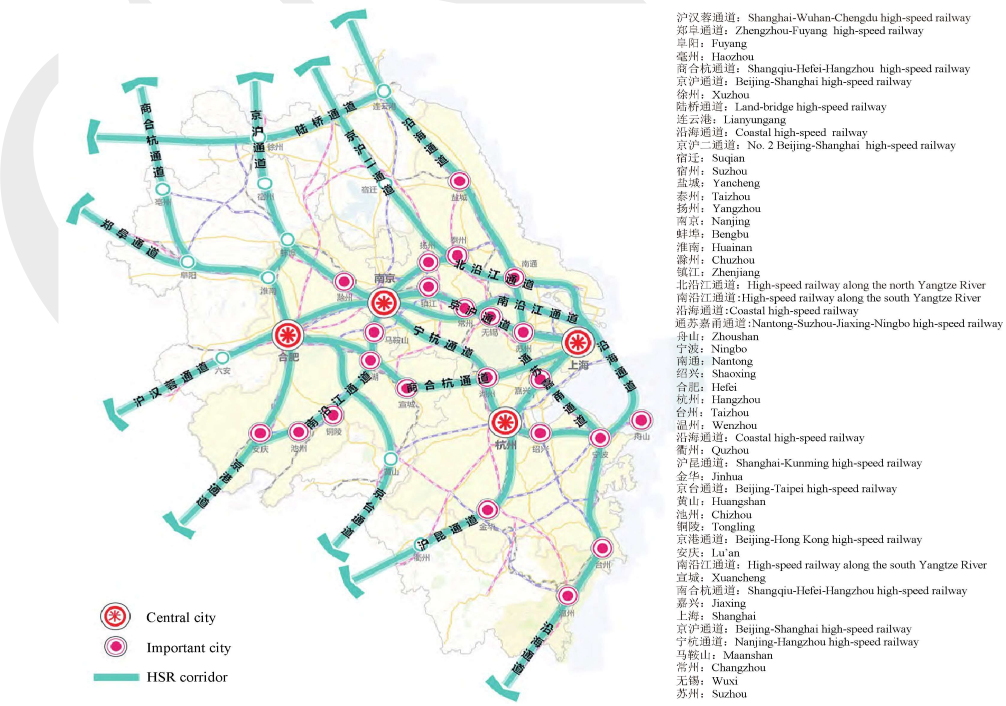


Fig. 5　Layout of the HSR corridor in the Yangtze River Delta

A typical case in which intercity railways in metropolitan areas are more responsible for connecting municipal functional areas is the Suzhou-Wuxi-Changzhou intercity railway. The planned Suzhou-Wuxi-Changzhou intercity railway will further make up for the shortcomings of the existing Shanghai-Nanjing intercity railway and strengthen the efficient connection of space and the convenient communication of personnel, and it fully embodies three optimization points: strengthening the service efficiency of the main axis of the corridor and optimizing the connection lines, coupling the direct access to the city center and matching the law of personnel flow, and realizing public transportation operation and highlighting the value of corridors and nodes. In the future, Jiading (Anting North Station) in Shanghai, Qingpu, Kunshan tourist resort (Dianshan Lake Station), Suzhou industrial park (Suzhou East Station), Suzhou HSR new town (Suzhou North Station), Suzhou new district, Wuxi Shuofang airport, Taihu Lake new town, Lihu lake area, and Changzhou HSR new town (Changzhou North Station) can all be connected in series through the Suzhou-Wuxi-Changzhou intercity railway (Fig. 6), which further reflects the functional node value of these regions for the city cluster.

4.2.2 Bottom-up: unified construction standards and patterns for urban rail transit and cross-over network operation

Urban rail transit is generally planned and constructed by the city government as the main body. In areas with continuously developed city clusters, the main axis of city development often coincides with the regional corridor, and the characteristics of passenger flows are basically the same. Therefore, urban rail transit should not only serve the passenger flow connection within the city but also fully consider the unified construction standards to realize cross-over network operation. For example, Huzhou is closely connected with Wujiang in Suzhou and Qingpu in Shanghai via Nanxun in the east, develops in an integrated way with Yuhang in Hangzhou via Deqing and Anji in the south, and has a cross-over connection with Yixing in Wuxi and Wujin in Changzhou via Changxing in the north. Similar integrated areas are common in the Yangtze River Delta. In the development of urban rail transit in Huzhou, the plan proposes to fully connect the intercity railways and the municipal (suburban) railway system of surrounding cities, and the east-west express line is taken as a part of the tourism line (Huzhou-Jiaxing-Hangzhou-Shaoxing line) in the region of rivers and lakes, which connects with the Rudong-Nantong-Suzhou-Huzhou intercity railway to jointly build an intercity network around Taihu Lake and realize through operation (Fig. 7).

The key to cross-over operations lies in regional coordination, so as to coordinate construction standards and patterns and reserve cross-line, overtaking, and intersection operation conditions. Therefore, it is possible to organize multi-intersection operations in different sections to reflect the difference in passenger flows and make intensive use of channel resources. In the process of this kind of bottom-up rail transit planning and construction, the whole line may not be implemented at one time, but in the future, it can be operated in a network according to the passenger flow demand.

It must be pointed out that even in a highly developed urban space system such as the Yangtze River Delta, advocating the two-network integration does not mean that all intercity railways and municipal (suburban) railways must undergo through operations. The mutual compensation between intercity railways and municipal (suburban) railways of metropolitan areas is conducive to the intensive use of channel resources, and a unified operation method is used to solve the rapid connection needs of urban-intensive areas without distinguishing between construction and operation entities. The premise is that the characteristics of passenger flow on this channel are similar, and the demand for

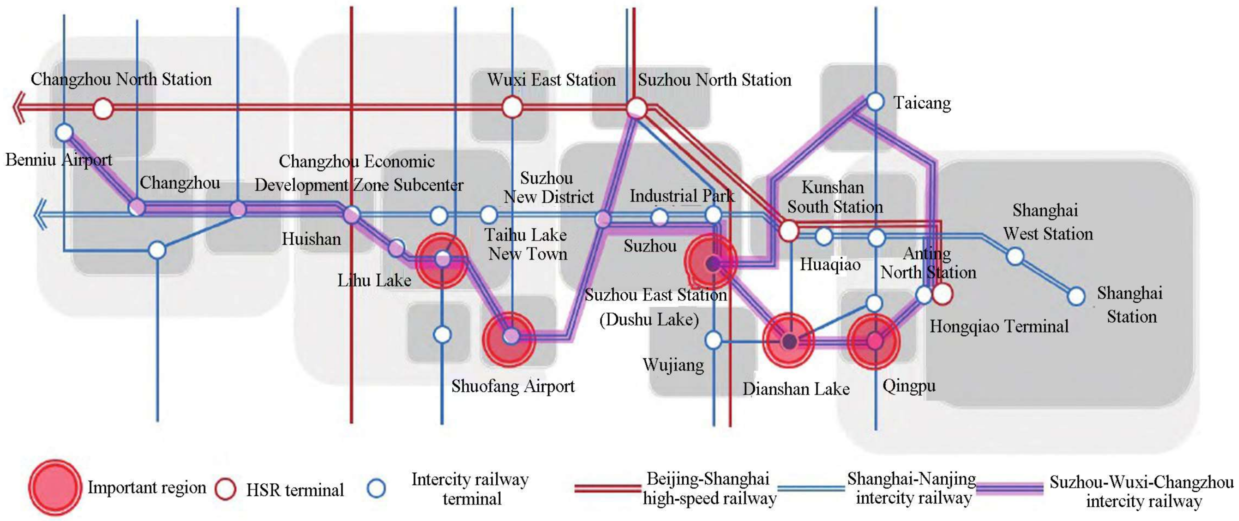


Fig. 6 Layout pattern of Suzhou-Wuxi-Changzhou intercity railway

cross-over traffic connections is strong, especially in urban-intensive areas. Furthermore, the passenger flow travel distance and speed expectations are relatively consistent and in line with the target speed and related technical characteristics of the rail system. In particular, channel resources are in short supply, and the passenger flow density is high on the city development axis, so it is very necessary to realize the two-network integration according to the actual situation. On this basis, it is necessary to strengthen the transfer and connections of the main-axis corridor and the city-level corridor at the same time and improve the terminal transfer level of intercity railways in metropolitan areas, municipal (suburban) railways, urban rail transit, and multi-level bus transportation systems, which are then supplemented by convenient ticket systems, transfer, and operation conditions, so as to truly realize the “one network” operation of the rail transit in metropolitan areas.

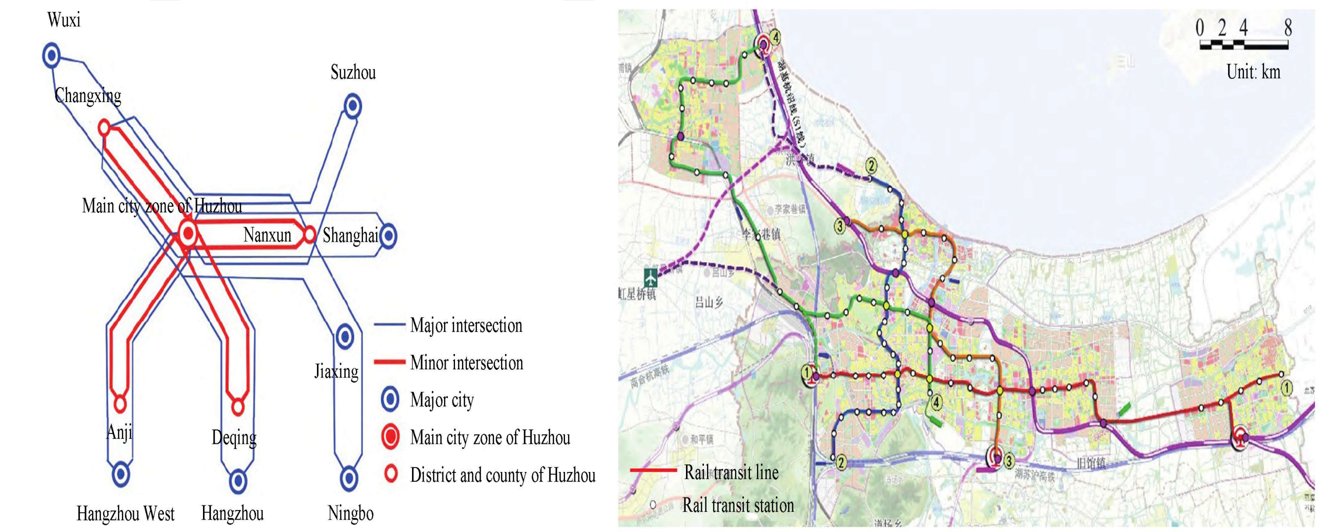
4.3 Path 2: realization of multi-network connection and station-city integration of intercity railway terminals

The planning and design of intercity railway terminals should be based on the scale of human activities. From the terminal to its surrounding areas, the proportion of intercity travelers is relatively high, and their activity spaces are expanded and integrated due to the existence of a large number of concentrated and regionally-oriented city functions, such as corporate headquarters, exhibitions, and trade. Therefore, it is necessary to continuously promote the integrated development of the terminal space and surrounding functional units, which has been fully confirmed in the Shanghai Hongqiao business district. In terms of the interior and connection of the terminals, it is necessary to reflect the demands of high-frequency and regular intercity business commuters, so as to realize the public transportation of the terminal ride and transfer, shorten the residence time in the station, and thus significantly improve the convenience and accessibility of areas around the terminal [4].

4.3.1 Terminal layout: shift from single-station radiation to multi-point layout

The number of railway passenger stations directly affects the internal service range and external reachable range of a station and further influences the collection and distribution mode of the passenger flow at the station. Europe and Japan have a large number of urban railway passenger stations, and these stations have shown obvious characteristics of short distance and high accessibility. The vast majority of passengers come from a certain range around the station, and their distribution can be easily analyzed by their dependence on public transportation, walking, and bicycles (Fig. 8). Therefore, the multi-point layout of railway terminals is conducive to promoting the positive integration of railway passenger stations and urban space.

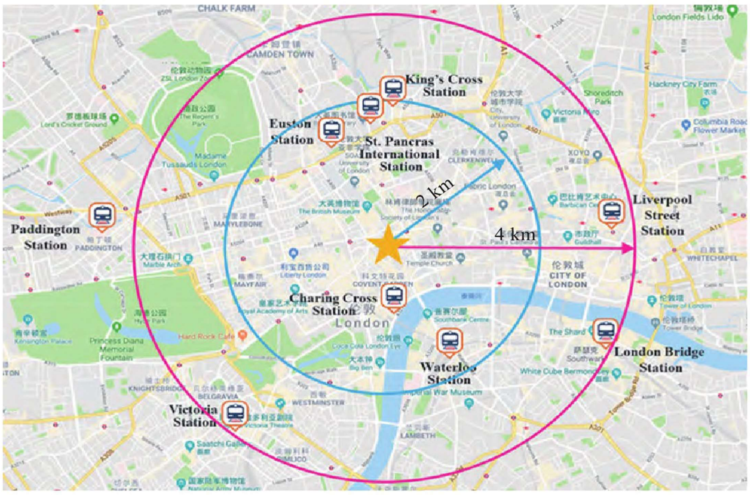
The planning and layout of the railway terminals should promote the four-network integration and facilitate the travel of passengers. From the planning of each city, it can be seen that the central cities in the Yangtze River Delta region are actively building a multi-terminal system. For example, Shanghai, Nanjing, Hangzhou, Hefei, Suzhou, and Wuxi have planned multi-level railway terminals. While promoting the efficient connection of multiple networks and convenient transfers, they are constantly optimizing the urban spatial structure and accelerating regional economic growth. In the future, in response to the multi-level rail transit network in the Yangtze River Delta, the railway terminals will gradually develop toward the layout of multi-point anchorage. More and more cities will form a multi-terminal pattern, and the goal of taking rail transit at the doorstep will be realized.



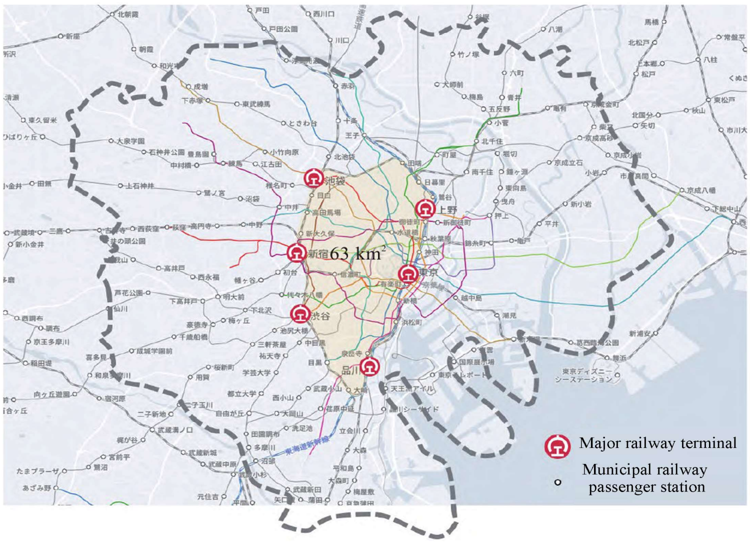
a Multi-intersection operation and organization

b Huzhou-Jiaxing-Hangzhou-Shaoxing line

Fig. 7 Examples of cross-over operation of urban rail transit in Huzhou



a The nine train stations in London are closely coupled with the main functional areas and activity areas



b Six major railway terminals in 23 districts of Tokyo and railway passenger stations all over the city

c Amsterdam in the Netherlands arranges two main railway terminals and nine secondary stations along the railway line

Fig. 8 Examples of multi-point layout of international urban railway terminals

4.3.2 Service mode: emphasis on connecting with urban rail transit, station-city integration, and efficient green mode

The railway terminal service mode under the four-network integration requires urban rail transit to play a core and backbone role in the collection and distribution system of railway passenger stations, which is also a key link in promoting the transformation of the "three networks" including trunk railways, intercity railways, and municipal (suburban) railways into “four networks”. From the existing network and planning situation, the cities with urban rail transit in the Yangtze River Delta will inevitably connect urban rail transit to railway terminals, and the number of access lines will further increase. For example, Shanghai Hongqiao Station and Suzhou North Station will have access to five urban rail transit lines in the future, and Hangzhou West Station will have access to four urban rail transit lines.

In addition to the four-network organic integration, the new railway terminal service mode should also highlight three requirements:

1) Terminal-space integration. In the future, intercity travel in the Yangtze River Delta should reflect convenience, efficiency, and time value. The service of railway terminals should meet the needs of “double shortness”, that is, the shorter travel distance of the railway section and the shorter collection, distribution, and connection distance of the terminal, which in essence brings closer communication and more convenient arrival. Therefore, it requires the railway terminals to shift from the station-city separation to the station-city integration in terms of the layout, from the grand station to the intensive station in terms of the scale, and from the collection and distribution square to the communication activity space in terms of the form [11] (Fig. 9).

2) Efficient public transportation operation. ① Shift from the schedule-based train to public transportation operation, which is suitable for corridors with dense passenger flows; break through the traditional railway operation and organization mode and swipe the card to buy a ticket to go, so as to the transfer of different levels of rail transit. ② Shift from waiting in the station hall to waiting on the station platform, which is suitable for medium-sized railway passenger stations and closer to the destination, and it can simplify the boarding procedures and improve the efficiency of railway travel. ③ Shift from single-line operation to network operation, which is suitable for networked spaces and high-density passenger flow areas in metropolitan areas, so as to achieve more flexible operation modes and diversified choices and organize major and minor intersections, fast and slow trains, and cross-line operations.

3) Green and low-carbon connections. Under the relatively single railway service mode, if a larger area and a longer connection distance are to be served, it is necessary to configure an elevated ramp for cars to ensure direct access to the railway passenger station, which results in low accessibility of non-motorized vehicles. Under the new service mode, the connection system of the terminal should give priority to the accessibility of green transportation, and the most convenient interface of the terminal should give priority to the connection, collection, and distribution of walking, non-motorized vehicles, and buses. With Amsterdam South Station as an example, at least one entry and exit interface is reserved for trams and bicycles for direct connection. At the same time, multiple pedestrian corridors connect different functional areas, making walking, cycling, and public transportation within a short connection distance become more reliable methods. This is exactly the function that is neglected in China’s current railway terminal connection system, but it should be given priority. In the future, it is necessary to optimize the convenience of walking and non-motorized vehicles’ access to terminals, improve the service efficiency and quality of connecting buses, and ensure the transfer and connection space of green transportation such as rail transit, buses, and non-motorized vehicles.

Fig. 9 Comparison of traditional station-city mode and station-city integration mode

5 New development mechanism of four-network integration

From the current development focus, the mechanism of China's railway planning and construction will gradually shift from national authority to local guidance. This mainly reflects the main contradictions and focus points at different stages: the national authority emphasizes the centralized solution to the transportation capacity of the trunk railways, so as to effectively guarantee and give full play to the supporting role of the railway in the development of the national economy; the local guidance pursues travel convenience and efficient operation under the background of high-quality development at this stage, reflecting the demands of local economic development and the new requirements of regional coordinated development. Railway planning and construction have shifted from national authority to local guidance, which is similar to the complementary development mechanism of Japan's state-owned and private railways. Japan's state-owned railways focus on solving the transportation capacity of the trunk lines, and the private railways solve the local commuting (mainly suburban railways) caused by suburbanization. The two have achieved interoperability within a certain range and reached a basically equivalent volume of transportation.

In the future, exploration and innovation in terms of three aspects should be carried out at specific mechanism construction:

1) Enterprise operation to seek a virtuous circle of investment and income. It is necessary to explore the establishment of railway construction or operation enterprises according to lines or regions, carry out the enterprise operation, and strengthen the virtuous circle among passenger flows, economic benefits, service level, and space value. Policy tools shall be employed to eliminate border barriers and achieve a win-win situation for cities and railway departments through enterprise operations. The comprehensive development planning of station lands shall be coordinated and formulated, and the development and utilization of lands need to be promoted. in addition, it is important to establish a comprehensive guarantee mechanism and use the comprehensive development revenue of lands to support railway project construction and operation.

2) Cross-regional collaboration to implement the cross-regional coordination mechanism of planning and construction. In the planning process, according to the situations of different subjects, it is essential to establish a joint application and planning coordination mechanism, jointly formulate operational rules, technical guidelines, and cooperation agreements for cross-regional collaboration, and determine the planning scheme and land use guarantee for the railway project. In the construction process, it is necessary to open investment and financing channels, explore and establish the railway project construction funds, and ensure the implementation of projects through regional co-financing or cost sharing.

3) Operational service cooperation to integrate the resource platforms and promote the integration of operations and services. It is important to explore how operators can promote the integrated operation of transportation resources at different levels in regions, metropolitan areas, and cities through marketization and materialization. In addition, we should encourage the establishment of service providers to promote and realize one-card travel and one-ticket ride between regions and between modes of transportation through platform construction. In the future, the Yangtze River Delta should realize an integrated ticket system to meet the one-ticket travel for railways and urban rail transit. For example, we can launch one-day, two-day, and three-day pass tickets or tourist traffic tickets for visitors and tourists, and regular commuters and business people can get a ride by one card to strengthen transfer discounts and payment convenience.

6 Conclusion

Promoting the four-network integration of trunk railways, intercity railways, municipal (suburban) railways, and urban rail transit is an inevitable requirement for promoting the coordinated development of city clusters and metropolitan areas. In the future, three aspects in the four-network integration development of China's major city clusters and metropolitan areas should be emphasized: first, we should build city clusters on the rail, pay attention to the changes in the demand characteristics of travelers in the whole travel chain, and optimize railway transportation supply and services based on demand; second, we should accelerate the network integration and terminal station-city integration and strengthen the construction of rail transit for metropolitan areas and railway terminals (groups) coupled with city centers rather than blindly pursue higher speeds and larger terminals; third, we should actively explore and establish a four-network integration development mechanism in the new era to help realize the win-win situation of city-railway-people.

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