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Urban Express Rail Transit Planning and Design

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Abstract: With the rapid urbanization and promotion of urban agglomeration in metropolitan areas in China, urban express rail transit lines have a rapid development trend. The express rail transit planning and design, as well as its construction and operation, are not satisfying in China, while the industry development is still evolving with significant issues to address. With a summary of planning and construction, operation performance, technical standards, and main problems in practical cases of urban express rail transit lines in China, this paper uses trend prediction, case analysis, and horizontal analogy to address several key issues, such as the interactive coordination between network planning of express rail transit lines and urban land use planning, appropriate construction timing adapted to urban development, and reasonable system formats and technical standards. The paper concludes that key factors to increase passengers flow and level of service of express rail transit lines include direct access to urban core areas, effective connections with different travel modes, and the network-based and high frequency operation of metropolitan railway. The paper also suggests scientifically developing a standard system of express rail transit lines and identifies main issues to be addressed in the future. **DOI:** 10.13813/j.cn11-5141/u.2021.0048-en

Keywords: rail transit; express rail transit; planning and design; system formats; technical standards

1 Current situation of urban rapid rail transit in China

1.1 Development overview

1) Operation.

According to statistics in the China Association of Metros (CAMET) annual report, as of December 2019, urban rapid rail transit (see Fig. 1) had been operational in 15 cities in China with a total of 36 lines [1], 1,330 km in distance, and an increase of 12.8% from 2018.

2) Construction.

As of December 2019, 67 urban rapid rail transit lines were under construction in 22 cities in China (some projects were approved by local governments and were not included in the statistics), with a total length of 2,603 km and an increase of 18.1% from 2018. The distances of urban rapid rail transit lines under construction exceed 200 km in Chengdu, Hangzhou, and Foshan, exceed 150 km in Beijing, Shanghai, Guangzhou, Wuhan, and Zhengzhou, and range between 100 and 150 km in Shenzhen, Dongguan, Chongqing, and Jinhua (excluding intercity railway) (see Fig. 2) [1].

1.2 Typical cases

Focusing on the urban rapid rail transit lines in operation and under construction, this article presents statistics and comparative analyses on major technical parameters of several typical projects (Tab. 1). The planned lines in all typical cases of urban rapid rail transit lines exceed 50 km and are large- or medium-capacity rail transit systems (except for special functional lines). The average distance between stations is typically 3–5 km. The maximum running speed is 120–160 $km\cdot h^{-1}$. Locomotive and car models include DC-traction trains for urban rapid rail transit and AC-traction metropolitan car styles A, B, C (including CRH EMU) and D. The operational organization adopts multiple modes, including a tracking operation mode with per-station stops and a mixed operation mode with express and local trains.

1.3 Benefits of passenger volume

The *Opinions of the General Office of the State Council on Further Strengthening the Management of Urban Rail Transit Planning and Construction* (GBF [2018] No. 52) provided specific instructions that "the ridership service intensity of proposed metro and light rail lines in the initial stage shall not be less than 7,000 rides and 4,000 rides per

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kilometer per day". Among 185 urban rail transit lines (excluding trams) at the end of 2018 [2], 18 urban rapid rail transit lines were selected as sample cases, with an average ridership service intensity of 1,700 rides·km^{-1}. Except for Guangzhou Metro Line 3 and Shenzhen Metro Line 11, the ridership service intensity of other lines was basically less than 4,000 rides·km^{-1} (see Fig. 3).

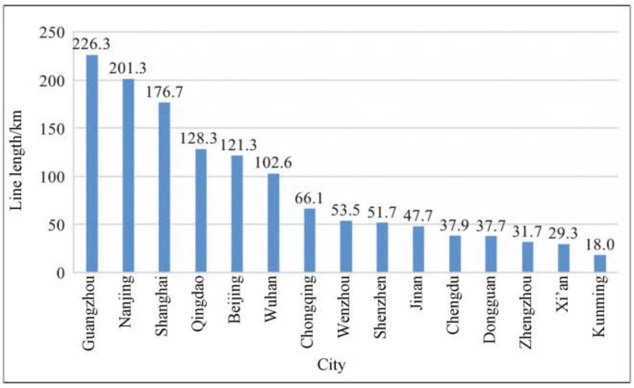

Fig. 1 Express rail transit lines in operation in Chinese cities in 2019

Source: *Statistical and Analysis Report of Urban Rail Transit in 2019*.

1.4 Main Issues in planning, construction, and operation

1) Given the needs of urban planning and urban development, one issue is how to accurately control the functional orientation, route layout, ridership forecast, implementation plan, and construction sequence of urban rapid rail transit lines in urban rail transit network planning, so as to avoid any substantial differences between the implemented and expected outcomes of planning and construction [3].

2) With the implementation of planned functions, the issue is how to systematically combine the urban rapid rail transit lines with urban spatial planning and land use, solve the planning control problem of colocated corridors and hub land in built-up areas, plan and build high-standard, high-quality, low-cost (construction and operation) and sustainable urban rapid rail transit lines, and achieve a win-win situation of urban planning development and rail transit construction and operation.

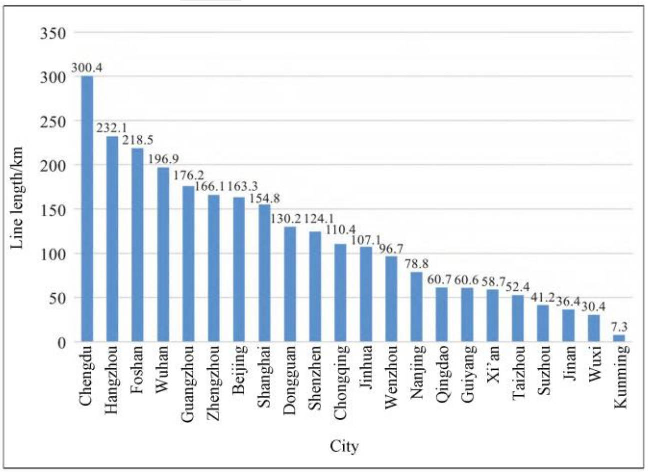

Fig. 2 Express rail transit lines under construction in Chinese cities in 2019

Tab. 1 Technical indicators of typical express rail transit lines in operation and under construction

City	Line	Length/km	Number of stations	Average station interval/km	Maximum running speed/ (km·h^{-1})	Car models	Operating mode	Long-term peak hour section predicted ridership/ (10,000 rides·h^{-1})
Beijing	Daxing Airport Line (Recent Extension)	41.4	3	20.7	160	Metropolitan car style D	Stop per station	0.64
	Pinggu Line	81.2	21	4.1	160	Metropolitan car style D	Express and local trains	4.70
Shanghai	Line 16	59.3	13	4.9	120	Style A train	Express and local trains	2.80
	Jiamin Line	68.8	9	8.6	160	CRH EMU	Express and local trains	
	Shanghai Airport Link	86.6	20	4.6	160	CRH EMU	Express and local trains	
Guangzhou	Line 3	64.4	30	2.2	120	Style B train	Stop per station	4.24
	Line 14	76.3	22	3.6	120	Style B train	Express and local train	2.90
	Line 18	61.3	9	7.7	160	Metropolitan car style D	Express and local trains	2.85
Shenzhen	Line 11	51.9	18	3.1	120	Style A train	Stop per station	5.09
Chengdu	Line 18	69.4	12	6.3	140	Metropolitan car style A	Express and local trains	3.15
	Line 19	62.7	19	3.5	140，160	Metropolitan car style A	Express and local trains	3.59
Qingdao	Line 11	58.4	22	2.8	120	Style B train	Stop per station	1.85
	Line 13	70.0	23	3.2	120	Style B train	Stop per station	2.24
Wenzhou	Line S1	53.0	18	3.1	120	Metropolitan car style D	Stop per station	2.30
Fuzhou	Fuzhou–Changle Airport Express	62.4	13	5.2	140	Metropolitan car style A	Express and local trains	2.55

Source: *Study on Key Technologies of Traffic Organization and Operation Management of Metropolitan Rapid Rail Transit*.

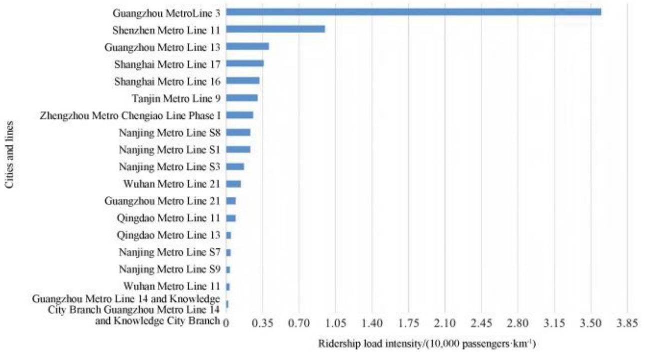

Fig. 3 Passenger flow volume of express rail transit lines in selected cities

Source: *Statistical and Analysis Report of Urban Rail Transit in 2018*.

3) The planning and development of urban rapid rail transit lines lag behind the construction of urban rail transit. How to properly plan for good connection between urban rapid rail transit lines and urban functional core areas and transportation hubs, as well as how to ensure operation efficiency, operation benefit, and service quality of rail transit network, is another important issue [4].

4) It is needed to improve the planning and construction of urban rapid rail transit (including suburban railways and intercity railways) and to balance the network-based and transit-oriented operation of intercity railways. Through the interaction and integration of rail transit construction and urban planning and development, the passenger volume level and sustainability of planned and constructed lines will be continuously improved, social and economic benefits will be enhanced, and the sustainable development of urban rapid rail transit will be achieved.

5) The definition and classification of urban rapid rail transit, metropolitan rapid rail transit, suburban railway, and intercity railway are not clear enough; the existing standards and codes fail to meet the needs of the rapid development of urban rapid rail transit [5].

2 Core issues in the planning and construction of urban rapid rail transit

2.1 Network planning and construction sequence

1) Is “metro rail transit first and rapid rail transit second; service coverage first and speed improvement second” the best and only preferred strategy?

As shown in China’s practice, the rail transit planning and construction in megacities (i.e., cities with population over 10 million) and supercities (i.e., cities with population of 5 to 10 million) generally cover and extend from the central city to the larger urban area. First, early-stage planning and construction are mainly for metros to address basic travel demand problems in the urban center. With spacial growth, cities usually adopt the approach of extending metro lines quickly and simply to meet the development and travel demand needs of peripheral areas, resulting in a typical 50–60 kilometers length of metro lines and a rapid development of China’s metro for 40 years with the construction scale exceeding that of all other international metropolises [6].

Compared with the rail transit systems of international metropolises, the urban rail transit of China’s megacities and supercities has weakness largely reflected in the line scale, operation efficiency, service quality, and investment benefit of the urban rapid rail transit system. For Shanghai’s early-stage rail transit network planning, SYSTRA, a French company, proposed a multi-level network planning of “metropolitan rapid rail transit lines+ metro lines” based on the experience of rail transit network planning in Paris. It was the first city in China to implement multi-level planning of urban rapid rail transit line (R line) and metro line (M line) in the urban rail transit network planning. After several rounds of rail transit construction planning, an operation network of nearly 1,000 km was developed in Shanghai. However, the originally planned R line has not been successfully developed according to the planning intention to form an efficient and convenient rail transit network system with a mixed operation mode using express and local trains. How to reshape a cost-effective and easy-to-transfer rail transit network system with a mixed operation mode using express and local trains has become an important subject in the development of urban rail transit in Shanghai.

2) How to solve the problem associated with the passenger volume benefits in the initial stage by “developing rapid rail transit before the metro lines and focusing on efficiency over benefits”?

With the rapid development of urban rail transit in China for 40 years, some cities implemented plans to connection urban rapid rail transit lines and other public transit before gradually building connection between urban rail transit in centralcity and metropolitan rapid rail transit lines or other public transit. These cities are either megacities with a multi-center cluster structure influenced by social and economic development or loose-structure multi-center cities formed under the division of mountains, rivers, lakes, or seas with small scale multi-center clusters and low traffic pressure. In order to enhance the attraction and priority of the central city, guide the development of urban space, and meet the increasing travel demand among clusters, the planning and construction of urban rapid rail transit is proposed. The framework of rail transit planned in these cities, such as Dongguan, Foshan, and Wenzhou, is based on urban rapid rail transit. However, the passenger volume benefits of urban rapid rail transit built in the early stage are generally unsatisfactory without a solid and convenient transportation connection system and policy system support.

3) “Future-oriented parallel development of the metro and rapid rail transit with focus on both efficiency and benefit” can be an ideal choice for the development of the urban rapid rail transit system.

Future-oriented planning and construction of the urban rapid rail transit can improve the efficiency of network-based operation and construction economy and also enhance the passenger volume benefits and urban planning and development. With balanced operation efficiency and passenger volume benefits, the goal of urban planning and sustainable development of rail transit can be achieved. Chengdu's rail transit development has lagged behind that of other first-tier cities for nearly 10 years. On the basis of analyzing and summarizing the experience of early rail transit planning and construction in first-tier cities, the exploration and attempt of the urban rapid rail transit development with the strategy of "future-oriented parallel development of the metro and rapid rail transit with focus on both efficiency and benefit" were carried out in Chengdu. Since the second revision of the rail transit network planning, Chengdu has proposed to build urban rail transit backbone lines while planning and constructing urban rapid rail transit lines. In the adjustment of the construction plan approved in 2015, Chengdu Metro Line 18 was planned and constructed on the north-south central axis to be paralleled to Line 1. On the one hand, this line shared the high passenger volume load of Line 1; on the other hand, it addressed the demand for urban space expansion to the south and east of the city. In the third and fourth rounds of construction planning, the connection between urban rapid rail transit network system and urban spatial structure and comprehensive transportation system will be further improved; in addition, four urban rapid rail transit lines, Line 13, Line 17, Line 18 Phase III, and Line 19, are planned for construction. Among them, Line 18 and Line 19 will be interconnected to efficiently and conveniently connect three urban core areas: Chengdu's main city center, Tianfu New Area center, and East New Town, as well as Shuangliu International Airport, Tianfu International Airport, Chengdu Railway Station, Chengdu South Railway Station, and Tianfu New Station.

Chengdu has also highlighted the importance of rail transit network that integrates national railways, m rapid rail transit, and urban rail transit to cover the whole area, and combines the metro and rapid rail transit, as well as the TOD construction that enables station-city integration to promote the sustainable development of urban rail transit. The rail transit network with 12 lines in operation of more than 519 km, as a whole, generates high passenger volume benefits and strongly supports Chengdu's expansion to the south and east of the city with a balanced regional development.

2.2 The Key to improving passenger volume benefits and service quality is the accessibility of city center and the convenience of traffic connection

Domestic and international experiences of planning and construction suggest three typical modes of connection between urban rapid rail transit and rail transit network in the central city: 1) single-point transfer of the urban rapid rail transit occurs at the edge or periphery of the central city; 2) the urban rapid rail transit enters a certain range of the central city to serve for multi-points transfer; 3) the urban rapid rail transit runs through the central area of the city [7]. The actual operation of urban rapid rail transit lines in China was assessed; the planning, construction, and operation experiences of urban rapid rail transit lines in Tokyo, Paris, New York, and London were also investigated. France's RER line crosses the central city; New York's commuter railway enters the Grand Central Terminal or a railway station in the core of the city; and Japan's metropolitan railway ring line, Yamanote Line, connects the center of Tokyo and several subcenters. All of these cases have shown good accessibility to the city center and convenience of connecting various modes of transportation, with network-based and high frequency operation. The following presents an analysis of the planning rationales and design features of China's Shenzhen Metro Line 11, which has characteristics of urban rapid rail transit and good passenger volume benefits, and Chengdu Metro Lines 18 and 19, which are operated based on network[8].

2.2.1 Shenzhen Metro Line 11

In June 2016, Shenzhen Metro Line 11 was open for operation, connecting Futian Central District, Qianhai and Houhai Central District, and the new Shenzhen Airport Terminal (see Fig. 4); it took 30 minutes from Futian Central District to the airport terminal. Line 11 directly connects urban functional core areas such as Futian, Qianhai, and Nanshan (the section extending eastward to Luohu is currently under construction; the connection with Dongguan rail transit is reserved northward). At the same time, Line 11 connects airports, railway passenger stations, and urban rail transit hubs including Shenzhen Airport, Qianhaiwan, Houhai, Chegongmiao, Futian, and enables connection and transfer to many urban rail transit lines. By July 2019, the average daily passenger volume was close to 500,000 rides·d^{-1} and the average one-way passenger volume at the highest section reached 33,100 rides·h^{-1}. After three years of operation, the passenger volume of Line 11 in its initial stage has reached the predicted short-term passenger volume level in the plan, with remarkable operational benefits. It is expected that after the extension of Line 11 to the core area of Luohu, passenger volume benefits will be further improved. In addition, the layout of Line 11 and the planning along the route were carried out in advance in 2005. With substantial land use constraint and the strongest east-west development momentum in Shenzhen, more than 20% of the route used elevated railway, which effectively controlled the initial investment and operating costs.

2.2.2 Chengdu Metro Line 18 and 19

Chengdu Metro Line 18 runs from North Railway Station to Tianfu New Airport through the central city and Tianfu New Area; it has mixed functions of urban rapid rail transit and airport express line, with a planned length of 86.6 km and 19 stations (Fig. 5). The major planned functions include 1) running in parallel with the existing Line 1 in the section of North Railway Station–Western China International Expo City Station (30 km) to share the long-distance commute volume on Line 1 and improve the operation efficiency; 2) achieving fast arrival from the downtown area to the new airport in 30–40 minutes; 3) sharing long-distance (35 km) rail operation with Line 19 from Tianfu New Station to Tianfu New Airport, serving the connection function for Chengdu Shuangliu International Airport and Tianfu International Airport. The first and second phases of Chengdu Metro Line 18 commenced in 2016 and were open in 2020. The Jiujiang North Station–Tianfu New Station section of Line 19 commenced in 2019 and is planned to be open in 2022 with a total length of approximately 42.9 km.

Fig. 4 Schematic diagram for Shenzhen Subway Line 11

Source: *Feasibility Study Report of Shenzhen Metro Line 11 Project*.

Chengdu Metro Line 18 is connected with three main railway passenger hubs and shared the route of Line 19 to connect two regional hub airports. The line connects urban core areas of the old town, the financial city of Tianfu New Area, and core areas of Tianfu Business District, and other urban functional core areas such as those of the East New Town. The first and second phases (South Railway Station–Tianfu International Airport North Station), which were planned to be built in the area of expansion to east and south in the city periphery, have been operational; the third phase (South Railway Station–North Railway Station), which is located in the main urban area of the city, is under construction. In September 2020, the early stage opening day passenger volume of the line was 83,600 rides·d^{-1} and gradually increased to approximately 136,300 rides·d^{-1} in February 2021. Significant improvement of passenger volume benefits is expected after the third phase is completed.

2.3 Planning and construction of economic and efficient suburban railways and intercity railways to achieve network-based and bus transit-like operation

In order to promote and support the development of urban agglomeration and metropolitan areas, effectively control the scale of investment in rail transit construction, and enhance the high-quality development of central cities in urban agglomeration and metropolitan areas, the National Development and Reform Commission issued the *Guiding Opinions on Promoting the Development of Suburban Railways* (FGJC [2017] No. 1173) in June 2017. In December 2020, the General Office of the State Council issued the *Opinions on Accelerating the Development of Suburban Railways in Metropolitan Areas* (GBH [2020] No. 116). Promoting the development of suburban railways in metropolitan areas can optimize the functional layout of cities, improve the coordinated development of large, medium, and small cities or towns, and expand effective investment. Developing suburban railways has substantial benefits in terms of effectively using the radiation-driven role of central cities, expanding the supply of public transport services, alleviating urban traffic

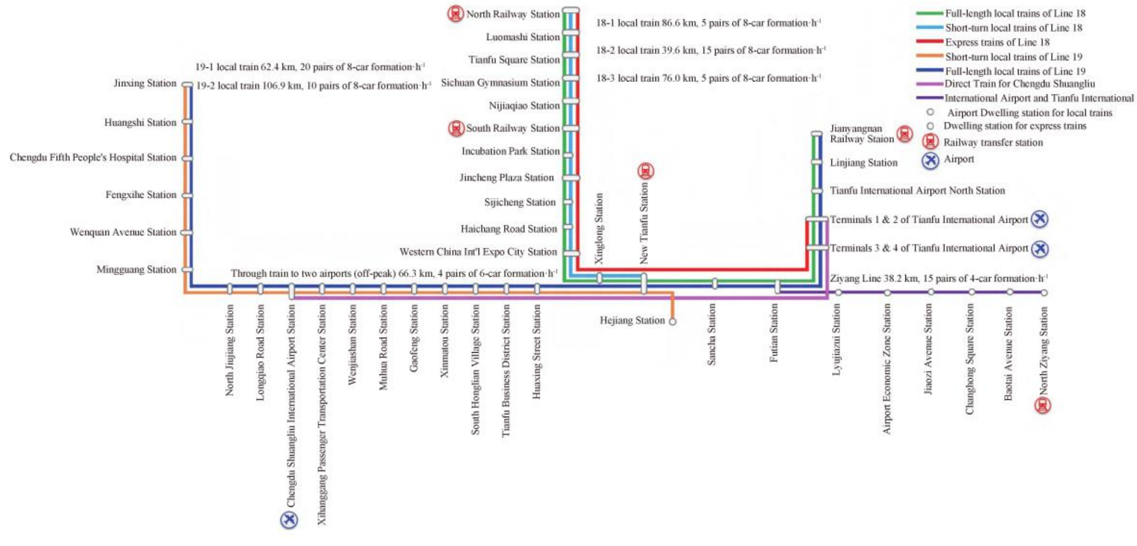

Fig. 5 Schematic diagram for the interconnectivity of Chengdu Subway Lines 18 and 19

Source: *Feasibility Study of Chengdu Metro Line 18 Project* and *Feasibility Study of Chengdu Metro Line 19 Project*.

congestion, and promoting the development of new urbanization. The key issue to achieve the development goal of suburban railway planning is whether the suburban railway can be built and operated economically and efficiently, can maintain a network-based and bus transit-like operation, and can provide passengers with transit services that allow for tickets purchase at any time and depart with flexible schedule and open seats. Another issue is whether it is possible to realize the compatibility of various ticket systems and ticket cards, as well as fast and convenient services such as time-metered and distance-metered fares or payment at exiting stations. Without addressing these issues, it is difficult to achieve the associated national policy objectives and requirements and may even divert from the original intention of the policy.

Therefore, "GBH [2020] No. 116" defines the main technical standards for newly-built suburban railway lines. The one-way transit time of suburban railways is required to remain less than 1 hour with a design speed of 100–160 km·h^{-1}; the average station interval is required to be less than 3 km in principle; and the headway during morning and evening peak hours are not allowed to exceed 10 minutes. The specific technical standards should be reasonably determined according to passengers demand, service scope, engineering conditions, land use standards, and so on. At the same time, the standards require coordination with requirements of ecological environment protection and the effects of engineering environmental protection measures, optimized site selection and route selection, and intensive and economical use of channel resources. A reasonable approach of new lines layout should be developed; for example, ground lines should be given priorities, the elevated mode can be considered for difficult sections, and underground mode can be studied for individual sections entering and leaving the hub. The project cost shall be strictly controlled; the direct project cost of new lines is required to be generally lower than 75% of the light rail project cost in the same area. These technical standards provide a new development direction of rail transit technology for urban rapid rail transit in urban agglomeration and metropolitan areas.

The development of the Guangdong-Hong Kong-Macao Greater Bay Area intercity railway (formerly known as the Pearl River Delta intercity railway) is an example to show that, due to the early and rapid social, economic, and urban development in the Greater Bay Area as strongly supported and promoted by the state, the planning and construction of the Pearl River Delta intercity railway progressed earlier than the emergence of the concept of the Guangdong-Hong Kong-Macao Greater Bay Area. The current six intercity railways are operated by China Railway Guangzhou Group Co., Ltd. (hereinafter referred to as "CR Guangzhou") and Guangzhou Metro Group Co., Ltd. (hereinafter referred to as "Guangzhou Metro") (see Tab. 2). There are 4–5 two-way trains running during peak hours on the Guangzhou–Huizhou Intercity Railway (Dongguan–Huizhou Section), which has the largest number of operating trains; other routes typically have 1–2 two-way trains; the passenger volume benefits are not sufficient, with the daily passenger volumes of 20,000–30,000 rides·d^{-1} on general routes. At present, operators are assessing measures to increase the number of two-way trains, improve service quality, achieve relevant national policy objectives, increase the attraction of passenger volume, and improve operational efficiency.

To accelerate the planning and construction of intercity railway projects in Guangdong Province and continuously improve the operation and management level, the Guangdong Provincial People's Government has adjusted the construction, operation and management approach for new intercity railways in the Guangdong-Hong Kong-Macao Greater Bay Area. Such approaches include promoting project planning and construction to adapt to the Guangzhou metropolitan area and the Shenzhen metropolitan area, as well as designating the metro enterprises in Guangzhou and Shenzhen to organize the implementation and operation, respectively.

According to the intercity railway construction plan for the Guangdong-Hong Kong-Macao Greater Bay Area, Shenzhen is comprehensively promoting the intercity railway construction in its metropolitan area. The main technical features of the proposed four intercity railway lines are shown in Tab. 3 (in the engineering design stage, CRH6 EMU has been

Tab. 2 Main technical features of current intercity railway lines in the Pearl River Delta

Railways	Sections	Operating length/km	Car models	Signal systems	Number of station	Average station interval/km	Design speed / (km·h^{-1})	Operated and managed by
Guangzhou–Zhuhai Intercity Railway	Guangzhou South–Zhuhai North	116	CRH1A, CRH6A/6F	CTCS-2	18	6.824	200	CR Guangzhou
Guangzhou–Foshan–Zhaoqing Intercity Railway	Guangzhou–Zhaoqing	111	CRH6A/6F	CTCS2+ATO	12	10.091	200	CR Guangzhou
Guangzhou–Huizhou Intercity Railway	Daojiao–Xiaojinkou	103	CRH6A	CTCS2+ATO	18	6.059	200	Dongguan–Huizhou section entrusted to CR Guangzhou
Guangzhou-Dongguan-Shenzhen Intercity Railway	Guangzhou East–Shenzhen Airport	74	CRH6A	CTCS2+ATO	16	4.933	140	CR Guangzhou
Zhuhai–Zhuhai Airport Intercity Railway	Gongbei–Changlong	16.86	CRH6A	CTCS2+ATO	6	3.4	160	CR Guangzhou
Guangzhou–Qingyuan Intercity Railway,Guangzhou East Ring Intercity Railway	Qingcheng Huadu, Huadu–Baiyun	38, 21	CRH6A	CTCS2+ATO	6, 3	7.6, 5.3	200	Guangzhou Metro

Source: *Report on Integrated Operation Plan of Intercity Railway and Metro in Guangdong-Hong Kong-Macao Greater Bay Area*.

determined; for the train control system of the Shenzhen–Huizhou intercity railway interconnected with the Pearl River Delta intercity railway, the CTCS or the CBTC compatible with the CTCS system is adopted).

The passenger volume benefits of the operational lines of Pearl River Delta intercity railway and the technical and economic indicators of the new Guangdong-Hong Kong-Macao Greater Bay Area intercity railway planning and construction are not satisfactory[9]. With rapid urbanization and economic development in the Pearl River Delta, the planning and construction of the intercity railways in metropolitan areas lags behind; as a result, although the construction conditions and economy of intercity railways in metropolitan areas are better along the peripheries or edges of cities, the passenger volume benefits are poor. In order to increase the attraction of passenger volume and improve the service quality of intercity railways in metropolitan areas, the route arrangement should involve urban functional core areas and important transportation hubs; however, the construction conditions and economy in these areas are poor. Based on historical analysis of the planning and development of suburban railways in international metropolitans such as Tokyo, New York, Paris, and London, early planning and land use control are needed for intercity railways in urban agglomerations and suburban railways in metropolitan areas to achieve ideal technical, economic, and passenger volume benefits of urban rapid rail transit; the planning and construction also need to synchronize or remain ahead to the urbanization process. China's metropolitan areas led by core cities with a population of over 10 million people have missed the opportunity of synchronous planning and construction. It is suggested that the planning and construction of economic and efficient suburban railways and intercity railways with bus transit-like operation be highly valued in the planning and development of urban agglomerations.

For the construction standards and modes of the intercity railways in China's developed metropolitan areas, it is necessary to further assess the bus transit-like operation and management mode. Especially, in planning and construction, detailed analysis and comparison are needed for the functional orientation of the lines, station planning, line laying modes, system formats, and main technical standards, etc. It is also necessary to further study the fare system and service, clearing, compensation for losses, and upgrade and retrofit in the life cycle of intercity railways and suburban railways that are operated cross-regionally with the network-based and bus transit-like operation mode, so as to truly realize the accessible, imperceptive, one-ticket-accessible high-quality service and sustainable development of regional rail transit. Furthermore, it is necessary to study how to achieve balance of the network-based and bus transit-like operation of the intercity railways between management and transportation capacity.

3 Technical standards of urban rapid rail transit

After 40 years of rapid development of urban rail transit in China, the development of metro and light rail transit has been relatively mature, while the development of urban rapid rail transit is only in the initial stage. Therefore, the existing system of codes and standards of urban rail transit or railways can no longer meet the development and operation requirements. Industrial, local and institutional standards have been promulgated recently to guide the construction practices of urban rapid rail transit projects to meet the needs of industrial development. However, in order to realize standardized, orderly, and healthy development of China's urban rapid rail transit by classification, it is necessary to summarize the best practices for at least 5–10 years to gradually improve the national and industrial standards that are suitable for the development of China's urban rapid rail transit.

3.1 Current standards for urban rapid rail transit

Different system formats are adopted for rail transit lines based on functional positioning and technical conditions. In addition to differences in technical characteristics, technical systems, and technical standards, various system formats also have differences in standards and requirements of project establishment, industry management, examination and approval system, investment and financing, and operation management [10].

Tab. 3 Main technical features of the planned intercity railway lines in Shenzhen Metropolitan Area of the Guangdong-Hong Kong-Macao Greater Bay Area

Railways	Sections	Line length/km	Car models	Train operation control system	Number of stations	Average station interval/km	Design speed/(km·h⁻¹)
Shenzhen–Dayawan Intercity Railway	Shenzhen Airport T4–Dayawan	72.2	CRH6 or metropolitan car style D	Moving block-compatible CTCS	10	8.0	160
Shenzhen–Huizhou Intercity Railway	Qianhai, Shenzhen–Huizhou	131.0	CRH6A/6F	Moving block-compatible CTCS	18	7.7	160
Longgang–Dapeng Intercity Railway	Airport Longcheng, Shenzhen–Xinda, Dapeng	39.4	CRH6 or metropolitan car style D	Moving block-compatible CTCS	6	7.9	160–200
Extension of Guangzhou-Dongguan-Shenzhen Intercity Railway	Shenzhen Airport–Huanggang Port	35.0	CRH6A	CTCS2+ATO	3	11.6	140

Source: *Feasibility Study of Dapeng Branch of Shenzhen–Huizhou Intercity Railway Project*.

In the classification of urban rail transit, a rapid rail transit system that covers urban areas (including inter-urban areas) and realizes bus transit-like operation and management can be defined as urban rapid rail transit system. However, including suburban railway and intercity railway, which are mainly used to serve for commuting in urban agglomerations or metropolitan areas, in the scope of urban rapid rail transit has not been clearly defined in policies and standards. With the promulgation of “FGJC [2017] No. 1173” and “GBH [2020] No. 116”, the integrated development of rail transit has become the development trend of the industry. Therefore, in this article, urban rapid rail transit, suburban railway, and intercity railway with bus transit-like operation are included in the standard system of urban rapid rail transit, as well as the standard of metro express, for analysis and comparison study.

The main indicators of relevant standards and specifications of urban rapid rail transit issued in China are shown in Tab. 4. The industry standard, “Design Standard for Urban Rapid Rail Transit” compiled by the Ministry of Housing and Urban-Rural Development, has also passed several rounds of consultation and expert review with upcoming approval and promulgation.

3.2 Main differences in technical standards of different system formats

The differences in technical standards for urban rapid rail transit, suburban railway, and intercity railway operated with bus transit-like operation are reflected in several aspects, such as car and gauge standards, train operation rules, passenger transportation organization in stations and ticketing system, signal system and train control, wireless communication system, system design capability, wiring between lines and stations or yards, effective platform length and standards of arrival-departure tracks, power supply system, disaster prevention and safe evacuation, and network operation.

The timely development and promulgation of existing standards have effectively guided the construction of urban rapid rail transit, but issues also exist in terms of inaccurate classification, unclear definition, unclear adaptation conditions, and overlapping and contradictory standards. With the promulgation of local standards, the problems of adaptability and authority become more prominent, which will create new problems for selecting implementation criteria associated with operation management, project supervision, review, and approval.

The core technical conditions of standards for urban rapid rail transit are car selection, train operation control system (hereinafter referred to as “TCS”), and traction power supply system. The technical conditions for cars mainly include structural property, dynamic performance, door type and quantity, carriage layout and seating capacity, and car comfortableness.

1) Car selection

Urban rapid rail transit has a long average transportation distance and large passengers volume, but its peak hour capacity requirement is generally lower than that of urban metro lines. Considering transportation capacity, urban rail transit car styles A and B (DC, AC), metropolitan car style D, and CRH EMU all meet the operation requirements. However, China’s standard intercity EMU has poor adaptability to the urban rapid rail transit with the demand of large-capacity bus transit-like service in terms of car traction and braking performance, overcrowding capacity, carriage layout, and door design. As a result, China’s major locomotive and rolling stock manufacturers have developed cars with their own intellectual property rights, including dual-mode urban EMU, metropolitan car style D, and metropolitan car style C (including CRH6 cars) suitable for bus transit-like operation, all of which are compatible with railway gauge. At the same time, the AC traction or AC/DC dual-mode metropolitan car styles A and B have been developed based on the urban rail

Tab. 4 Main indicators in relevant published standards and specifications for express rail transit lines in China

Specifications	Issued by	Speed level/(km·h^{-1})	Car models and traction power supply system	Signal systems	Minimum headway/min	Interval of stabling sidings for dead train/km
Code for Design of Intercity Railway (TB 10623—2014); Code for	National Railway Administration	120–200	CRH EMU, AC	CTCS	3.0	20–30
Design of Suburban Railway (TB 10624—2020)	National Railway Administration	100–160	Metropolitan car style A and B, AC or DC Metropolitan car style C and D, AC	CTCS, CBTC	3.0, 2.5	≤20
Code for Design of Suburban Railway (T/CRS C0101—2017)	China Railway Society	100~160	Metropolitan car style A and D and CRH EMU, AC	CTCS, CBTC	2.5	≤15
Technical Specification of Metropolitan Rapid Rail Transit (T/CAMET 01001—2019)	China Association of Metros	100–160	Metropolitan car style A, B, D, DC or AC; medium- and low-speed maglev, linear motor	CTCS, CBTC	2.5	About 15
Guidelines for Planning and Design of Urban Rapid Rail Transit (RISN-TG032—2018)	Ministry of Housing and Urban-Rural Development	100–160	SK-A, SK-B, AC or DC	CBTC	2.5	15 for general 20 for unfavorable conditions
Code for Design of Shanghai Suburban Railway (T/SHJX 002—2018)	Shanghai Transportation Trade Association	100–160	CRH6F EMU, AC	CTCS-2	3.0	20–30
Code for Design of Metropolitan Rapid Rail Transit System (T/CCES2—2017)	China Civil Engineering Society	120 160	Metropolitan car style A and B, AC or DC Metropolitan car style D, AC	CTCS, CBTC	2.5	About 15
General Technical Specification for 120 km/h–160 km/h Commuter Express of Urban Rail Transit System (GB/T 37532—2019)	Standardization Administration of the People’s Republic of China	120–160	Metropolitan car style A, B, and D, AC			

transit cars to adapt to the operating characteristics of urban rapid rail transit with high designed max speed and large station interval, so as to realize the gauge compatibility and resource sharing with urban rail transit lines.

With the planning, construction, and technical development of urban rapid rail transit, the choice of system formats becomes more flexible and diverse. In the planning and design of urban rapid rail transit, car selection should be determined based on economy and efficiency principles from the perspective of network planning and operation, combined with the functional orientation and technical conditions of the lines. It is necessary to classify the urban rapid rail transit from the national and industry management perspectives, further standardize and clarify the classification standards, and make the technical standards standardized and serialized on the basis of urban rail transit classification standards.

2) Signal and train control system

The selection of signal systems should consider safety, maturity, reliability, high efficiency, economy, and applicability to meet the needs of transportation capacity and bus transit-like operation. Relevant national, industrial, and organizational standards have defined specific technical requirements for the signal system of urban rapid rail transit. The main signal and train control systems are categorized into two groups: CTCS signal system and CBTC signal system. Taking intercity EMU with 8-car formation as an example, the effective length of arrival-departure tracks using a CTCS signal system shall not be less than 400 m; the length, however, can be reduced to approximately 230 m for the moving block train control system using CBTC signal system of urban rail transit. In addition, the maximum driving capacity with the CTCS signal system does not exceed 20 pairs·h^{-1} and the maximum driving capacity with the CBTC signal system can be increased to 24–30 pairs·h^{-1}.

3) Traction power supply system

Comprehensive project-scale comparison and selection of technology and economy are required for urban rapid rail transit to determine the traction power supply system suitable for different functional positioning and line conditions. Three factors should be considered in the selection of traction power supply system: 1) the economy and feasibility of the traction power supply system; 2) the impact of traction power supply system on civil engineering investment; 3) whether the structure gauge of tunnels determined by the selected traction power supply system meets the requirements of the blockage ratio of tunnels. The needs for network operation and resource sharing should also be considered.

3.3 Suggestions on establishing technical standard system for urban rapid rail transit

1) National or industrial standards for rail transit classification need to be developed as soon as possible based on national management of the rail transit industry to further standardize and clarify the classification of urban rapid rail transit; the associated technical standards also need to be compiled according to scientific and authoritative classification.

2) It is recommended to classify the technical standards of urban rapid rail transit into two categories based on the municipal engineering industry and railway engineering industry and three speed levels according to the maximum running speed: urban rapid rail transit, metropolitan rapid rail transit/suburban railways, and intercity railways (regional rapid rail transit) (see Fig. 6). Among these levels, urban rapid rail transit and metropolitan rapid rail transit are included in the municipal engineering industry standard, while suburban railways and intercity railways are included in the railway industry standard. In this way, a scientific and standardized technical standard system for urban rapid rail transit can be constructed to avoid poor implementation due to overlapping or unification of various standards.

3) China's urban rapid rail transit is in the initial development stage with insufficient relevant codes and standards. The applicability and authority of different levels of standards of urban rapid rail transit should be determined based on national standards, industrial standards/group standards, local standards, and enterprise standards/project standards. At the same time, it is suggested that the upper-level standards should be upgraded by continuously summarizing and improving the engineering practical experiences of the lower-level standards, so as to form the technical standard system of urban rapid rail transit as soon as possible.

4 Conclusions

Given the need for meeting the travel demand in metropolitan areas, core cities with populationover 10 million people, and super-large (mega) city clusters, urban rapid rail transit in China has great development potential in the future [9].

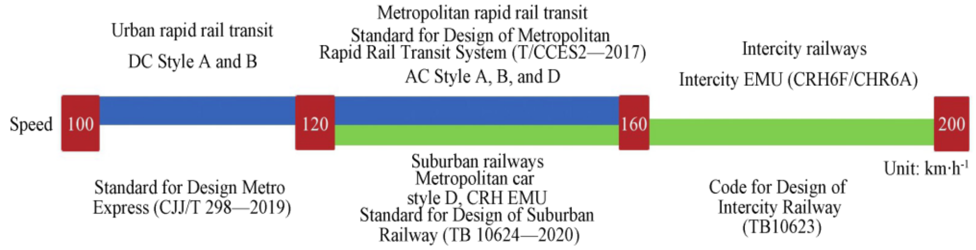

Fig. 6 Technical standard systems for urban rail transit lines, express rail transit lines, metropolitan railway, and intercity railway

Urban rapid rail transit has already broken through the boundary of a single administrative region (cross-urban regional rapid rail transit). In the future, three systems will be formed: a large-capacity express system of urban rail transit with a maximum running speed of 100–120 $km \cdot h^{-1}$ and the commuter passenger service function for cities with population over 10 million people; the large and medium-capacity transportation system of urban rapid rail transit with a maximum running speed of 120–160 $km \cdot h^{-1}$ and functions of commuting, business, and leisure travel; and cross-city express lines or intercity railways with a maximum running speed of 160–200 $km \cdot h^{-1}$ and functions of commuting and business travel in metropolitan areas and urban agglomerations. With the expansion of commuter circles in the cities with populationover 10 million people, metropolitan areas, and urban agglomerations, urban rapid rail transit will have multi-level and multi-standard characteristics. Based on the characteristics of passenger volume demand and line conditions, the operation organization will include mixed operation with express and local trains, network-based cross-line operation, and multi-routing main and branch lines.

The following issues in planning and construction practices of urban rapid rail transit should be focused on in further studies:

1) Based on national industry management, the scientific classification of urban rail transit and metropolitan (regional) rapid rail transit systems need to be further assessed to avoid functions overlapping and properly construct and continuously improve the corresponding technical specification system.

2) The coordination among different administrative regions and departments should be enhanced to effectively strengthen the leadership and control of cross-regional rail transit network planning; maintaining a sustainable development of urban rapid rail transit should be a consistent strategy and relevant policies or mechanisms need to be gradually established and improved.

3) To improve the passenger volume benefits and service quality of urban rapid rail transit, the functional positioning of transit lines, stations layout, population, and employment should be studied to achieve effective planning and coordination. Direct access to urban core areas and effective connections with different travel modes by urban rapid rail transit should be enabled.

4) With the development of cities, metropolitan areas, and urban agglomerations, the following measures are needed: properly select the system formats of urban rapid rail transit; strictly control the system scale and construction standard; advance the construction of urban rapid rail transit appropriately; and assess the economic and efficient management mode for constructing and operating urban rapid rail transit.

5) The coordination and interaction among urban rapid rail transit planning and construction, urban planning, and land use need to be highlighted to promote a win-win situation of rail transit construction and urban development. In addition, the study of sustainable development mechanism of urban rapid rail transit is needed and necessary resources should be allocated to balance the life cycle cost and set foundation for the sustainable development of urban rapid rail transit.

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