

Composition of Multi-Level Rail Transit System and Analysis of Interconnected Operation Modes

Hong He, Kangni Liu

Guangzhou Railway Polytechnic, Guangzhou, China
Email: 18802069165@163.com

How to cite this paper: He, H. and Liu, K.N. (2026) Composition of Multi-Level Rail Transit System and Analysis of Interconnected Operation Modes. *World Journal of Engineering and Technology*, 14, 124-133.

<https://doi.org/10.4236/wjet.2026.141007>

Received: December 5, 2025

Accepted: January 2, 2026

Published: January 5, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

With the rapid development of rail transit systems, a multi-level integrated rail transit network consisting of trunk railways, intercity railways, suburban railways, and urban rail transit has taken shape in metropolitan areas and megacities (abbreviated as “Four-Network Integration”). Different types of rail transit vary in service scope and operational characteristics. Taking the rail transit in the Guangdong-Hong Kong-Macao Greater Bay Area as the research object, this paper explores the composition of the multi-level rail transit system, the classification of interconnected operation modes, as well as their advantages and disadvantages, aiming to provide reference for the interconnected operation of rail transit.

Keywords

Rail Transit, Interconnection, Operation Mode

1. Composition of the Multi-level Rail Transit System

1.1. Trunk Railways

In terms of service scope, trunk railways include high-speed railways and conventional railways, providing medium and long-distance passenger and freight transportation nationwide. Generally covering a spatial scale of over 300 km, they mainly serve travel purposes such as business trips, tourism, work, and study. In terms of operational characteristics, trunk railways typically adopt long marshalling, fixed train operation plans, and stop at major stations with an average station spacing of 30 - 60 km. Conventional railways operate at speeds of 120 - 160 km/h, mainly running K, T, and Z-class conventional trains along major regional passenger corridors. High-speed railways operate at speeds of 250 - 350 km/h, dom-

inated by G-class high-speed EMUs and supplemented by D-class EMUs, connecting various urban agglomerations.

As one of the world's four major bay areas and one of China's four planned super urban agglomerations, the Guangdong-Hong Kong-Macao Greater Bay Area is located in the Pearl River Delta along the coast. Unlike inland cities such as Xi'an, Zhengzhou, and Wuhan, which are constructing "rice-shaped" high-speed rail networks, the Greater Bay Area excels in building fan-shaped radial high-speed rail networks to achieve efficient interconnection with inland hinterlands. Major trunk railway lines in the region include the Beijing-Guangzhou Railway and the Guangzhou-Shantou High-Speed Railway.

1.2. Intercity Railways

In terms of service scope, intercity railways mainly serve intercity travel such as business and tourism between urban clusters within a metropolitan area, generally covering a range of 100 - 300 km. In terms of operational characteristics, intercity railways usually adopt mixed long and short marshalling, relatively fixed train operation plans, and stop at major stations with an average station spacing of 5 - 20 km. Operating at a maximum speed of 160 - 250 km/h, they mainly use C-class intercity EMUs. Intercity railways always focus on less frequent travel for intercity.

Currently operating intercity railway lines in the Guangdong-Hong Kong-Macao Greater Bay Area include the Guangzhou-Shenzhen Intercity Railway, Guangzhou-Qingyuan Intercity Railway, Guangzhou-Zhaoqing Intercity Railway, and Guangzhou-Huizhou Intercity Railway, as detailed in **Table 1** below.

Table 1. Operated intercity railway lines in the Guangdong-Hong Kong-Macao Greater Bay Area.

No.	Intercity Railway Line	Operational Mileage in the Greater Bay Area (km)	Operating Entity
1	Guangzhou-Shenzhen Intercity Railway	147.0	China State Railway Guangzhou Bureau Group Co., Ltd.
2	Guangzhou-Zhuhai Intercity Railway	115.6	China State Railway Guangzhou Bureau Group Co., Ltd.
3	Dongguan-Huizhou Intercity Railway	103.1	Guangzhou Metro Group Co., Ltd.
4	Guangzhou-Dongguan-Shenzhen Intercity Railway	76.0	China State Railway Guangzhou Bureau Group Co., Ltd.
5	Guangzhou-Qingyuan Intercity Railway	38.2	Guangzhou Metro Group Co., Ltd.
6	Guangzhou East Ring Intercity Railway	78.0	Guangzhou Metro Group Co., Ltd.
7	Zhuhai-Jiuzhou Intercity Railway	16.9	China State Railway Guangzhou Bureau Group Co., Ltd.
8	Guangzhou-Zhaoqing Intercity Railway	34.0	Guangzhou Metro Group Co., Ltd.
9	Guangzhou-Foshan South Ring Intercity Railway	35.0	Guangzhou Metro Group Co., Ltd.
10	North Extension of Guangzhou-Qingyuan Intercity Railway	19.7	Guangzhou Metro Group Co., Ltd.

Continued

11	Foshan-Dongguan Intercity Railway	36.7	Guangzhou Metro Group Co., Ltd.
12	Phase II of Zhuhai-Jiuzhou Intercity Railway	22.4	China State Railway Guangzhou Bureau Group Co., Ltd.

1.3. Suburban Railways

In terms of service scope, suburban railways serve commuter transportation from the periphery of metropolitan areas to the central urban area. Some cities have extended the service scope of suburban railways to the central urban area in their planning, forming rapid high-capacity railway express lines for the central urban area. Typically, their service radius ranges from 40 to 50 kilometers. In terms of operational characteristics, suburban railways can adjust train intervals according to passenger flow patterns, operating a mix of express trains (stopping at major stations) and local trains (stopping at all stations). With an average station spacing of 3 - 8 km and a maximum speed of 120 - 160 km/h, they provide medium and short-distance rapid rail transit services for the central urban area and surrounding regions.

Taking Guangzhou as an example, Guangzhou Metro Line 18 (Xiancun Station-Wanqingsha Station), operated by Guangdong Intercity Railway Operation Co., Ltd., adopts 8-car D-type trains with a maximum speed of 160 km/h. With a total length of 58.3 km, it connects downtown Guangzhou with Nansha District and belongs to the suburban railway category. Guangzhou Metro Line 22, also operated by Guangdong Intercity Railway Operation Co., Ltd., uses 8-car D-type trains with a maximum speed of 160 km/h and a total length of 30.8km, classified as a suburban rapid rail transit line. At Guangzhou South Railway Station, this line connects with Guangzhou Metro Line 2, Guangzhou Metro Line 7, and Foshan Metro Line 2, making Guangzhou South Railway Station an integrated “four-network integration” transfer hub integrating high-speed rail, metro, suburban railway, and urban rail transit. Generally, suburban railways usually serve for daily commuting.

1.4. Urban Rail Transit

In terms of service scope, urban rail transit mainly undertakes large-capacity urban transportation needs in the central urban area, serving daily travel such as commuting and schooling within the main urban area, generally covering a city radius of 10 - 20 km. In terms of operational characteristics, urban rail transit usually operates local trains stopping at all stations. With the expansion of cities to the suburbs, some urban rail transit lines also operate express trains stopping at major stations. For example, Guangzhou Metro Line 21, with a total length of 60.4 km, adopts 6-car B-type trains and a mixed operation mode of express and local trains, with a maximum operating speed of 80 - 120 km/h. The urban rail transit system generally consists of metro, light rail, monorail, tram, etc., to meet large-capacity urban transportation needs.

As of December 31, 2024, cities in the Guangdong-Hong Kong-Macao Greater Bay Area with operational urban rail transit include Guangzhou, Shenzhen, Foshan, Dongguan, Hong Kong, and Macao, with a total operational mileage exceeding 1600 km (Table 2).

Table 2. Statistical data of urban rail transit operational mileage in the Guangdong-Hong Kong-Macao Greater Bay Area.

No.	City	Operational Mileage (km)	Number of Lines	Number of Stations
1	Guangzhou	683.58	17	317
2	Shenzhen	595.1	17	417
3	Foshan	120.47	3	54
4	Dongguan	37.8	1	15
5	Hong Kong	245.1	10	-
6	Macao	12.5	1	-

In summary, the service scope and operational characteristics of the multi-level rail transit system composed of trunk railways, intercity railways, suburban railways, and urban rail transit are highly correlated. Based on domestic research and practice, the main characteristics of the multi-level rail transit system are summarized in Table 3 below [1]-[3].

Table 3. Main characteristics of the multi-level rail transit system.

Rail Transit Level	Functional Orientation	Service Scope	Design Speed (km/h)	Station Spacing (km)	Bus Rapid Transit (BRT) Level
Trunk Railway	High-speed Railway	Undertake medium and long-distance passenger and freight transportation between urban agglomerations, provinces, and cities nationwide	>300 km	250 - 350	30 - 60
	Conventional Railway		120 - 160	10 - 50	Low
Intercity Railway	Undertake intercity travel between the metropolitan area and other cities within the urban agglomeration	100 - 300 km	160 - 250	5 - 20	Medium-Low
Suburban Railway	Undertake commuter transportation from the periphery of the metropolitan area to the central urban area within the municipal area and surrounding regions	40 - 50 km	120 - 160	3 - 8	Medium-High
Urban Rail Transit	Undertake passenger transportation needs in the central urban area	0 km	80 - 120	0.5 - 1	High

2. Classification of Interconnected Operation Modes

Scholars have conducted research on the interconnected operation modes of multi-level rail transit systems. Reference [4] classifies the operation modes into two types: shared-line operation and paid-area transfer at node stations. References [5] [6] divide them into shared-line operation mode and hub transfer mode. Most existing studies sort out and classify the interconnected modes based on the connection methods of passenger flow and train flow between different levels of lines, such as passenger transfer and cross-line train operation. In this paper, the operation modes are classified into four types according to the connection methods between lines: shared-line and shared-track operation, separate-line operation, cross-line operation, and connected-line operation.

2.1. Shared-Line and Shared-Track Operation

Shared-line and shared-track operation refers to an operation organization method where local trains (stopping at all stations) and express trains (skipping stations) operate on the same line, with express trains overtaking local trains at stations equipped with passing tracks. This operation mode shortens passengers' travel time to a certain extent and is suitable for lines with uneven passenger flow distribution, such as suburban lines and airport lines. However, passing stations need to add passing tracks and expand station scale, increasing project volume and investment; additional guiding signs required for shared-line and shared-track operation must be installed; and the operation organization becomes more complex.

Guangzhou Metro Line 21 adopts an operation mode of mixed express/local trains and short/long routes. The entire line has 20 stations, among which express trains only stop at Tianhe Park Station, Tangdong Station, Huangcun Station, Tianhe Smart City Station, Shenzhou Road Station, Suyuan Station, Shuixi Station, Zhenlong Station, Fenggang Station, and Zengcheng Square Station. Meanwhile, short-route trains running from Tianhe Park to Shuixi are operated during peak hours (Figure 1).

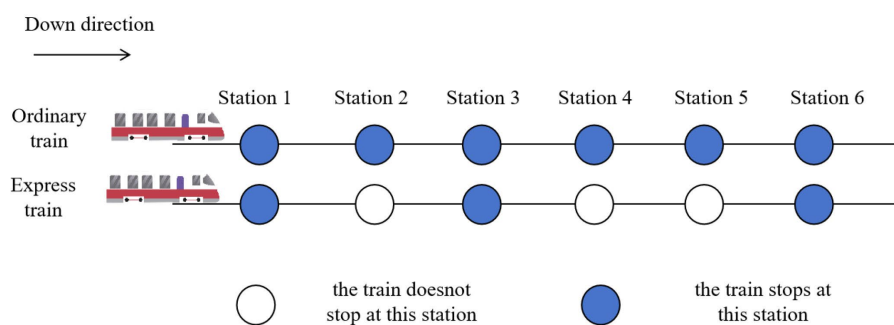


Figure 1. Schematic diagram of express/local train operation under shared-line and shared-track mode.

2.2. Separate-Line Operation

Separate-line operation mode refers to an operation mode where trains of differ-

ent speed levels operate simultaneously on their respective tracks within the same corridor. These can be trains with different operating speeds or different numbers of stopping stations. Express and local trains run on separate track lines and are connected through transfer facilities. The separate-line operation mode requires more than 4 tracks, with express and local trains forming independent systems, reducing the impact on operation organization and improving flexibility and single-line transportation capacity. However, separate-line operation has higher requirements for corridor space, resulting in significantly increased construction and operation costs. As shown in **Figure 2**. A prominent international example of a rail transit system with separate rapid and local services is the JR Chūō Line in Tokyo, which adopts a four-track parallel layout. Two main tracks are dedicated to the Chūō Line rapid trains (stopping at selected stations, with a maximum speed of 110 km/h), while the two side tracks are used for the Chūō-Sōbu Local Line (stopping at all stations, with a maximum speed of 80 km/h). The rapid and local lines are physically separated, ensuring that their operations do not interfere with each other.

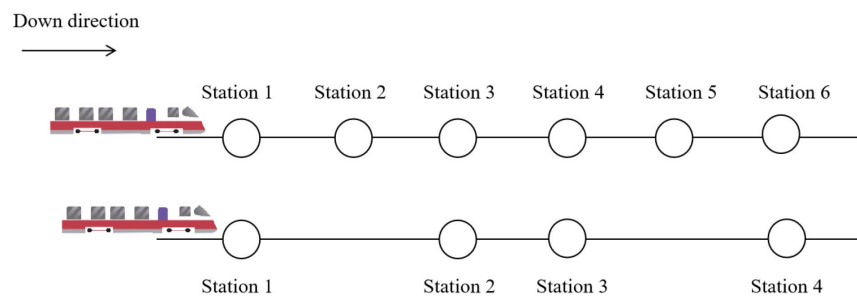


Figure 2. Schematic diagram of separate-line operation mode.

2.3. Cross-Line Operation

Cross-line operation refers to an operation mode where rail trains run on different lines without downgrading or decelerating during the operation period. After cross-line operation, there is a loss of transportation capacity on the original line and an increase on the connected line. Cross-line operation can effectively reduce the number of resources allocated, such as depots, vehicles, and train drivers, alleviate passenger flow pressure at transfer stations, shorten passengers' travel time, and improve the flexibility of operation organization. For lines with small train intervals, cross-line operation will increase the difficulty of operation organization. Therefore, it is not applicable to urban rail transit lines in the central urban area. For suburban lines with large transfer passenger flow between the central urban area, the feasibility of the cross-line operation mode can be studied. On December 28, 2021, the cross-line direct express train of "Chongqing Metro Line 4-Loop Line-Line 5" was put into operation. Line 4 and Loop Line realize cross-line connection at Min'an Avenue Station, and Loop Line and Line 5 at Chongqing West Railway Station, making Chongqing the first city in China to realize three-line cross-line operation (**Figure 3**).

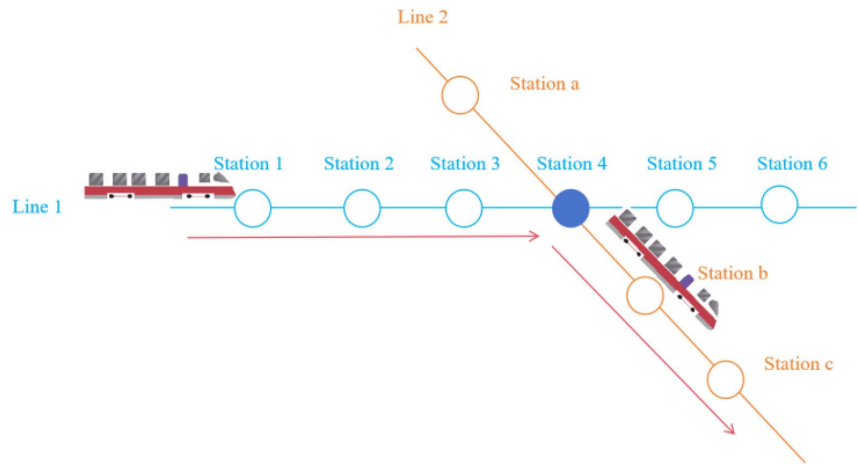


Figure 3. Schematic diagram of cross-line operation.

2.4. Connected-Line Operation

Connected-line operation refers to an operation organization method where suburban and urban rail transit lines of different standards (or marshalling) and operating speeds are connected end-to-end at transfer stations, also known as feeder operation. Different from cross-line operation, connected-line operation involves directly connecting lines end-to-end, and is suitable for suburban lines and urban lines with large transfer passenger flow at the starting stations. For example, on May 26, 2024, the Guangzhou-Huizhou Intercity Railway and Guangzhou-Zhaoqing Intercity Railway realized through operation at Panyu Station (Figure 4, Figure 5).



Figure 4. Connected-line operation of Guangzhou-Huizhou Intercity Railway and Guangzhou-Zhaoqing Intercity Railway at Panyu Station.

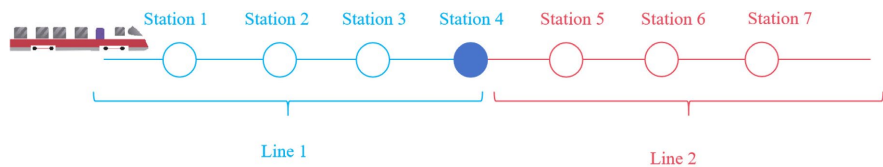


Figure 5. Schematic diagram of connected-line operation.

3. Analysis of Characteristics of Interconnected Operation

3.1. Advantages of Interconnected Operation

(1) Diversified train operation methods, enhancing the flexibility of transportation organization. Single-line operation and shallow-level networked operation are restricted by lines and can only operate on the original line. Changes in operation organization methods are merely variations in train routes. Due to limitations in turning-back conditions, problems such as uneven passenger flow distribution among different train routes and waste of transportation capacity in some sections often arise. The interconnected operation mode enables cross-line operation, express/local train operation, etc., enriching the forms of operation organization.

(2) Optimizing transfer methods at transfer stations and alleviating passenger flow pressure at bottleneck transfer stations. Under the original operation organization method, passengers need to go through the process of “alighting + walking + waiting” to transfer from one line to another. With the interconnected operation mode, the transfer method is transformed from “passenger transfer” to “train transfer”, reducing the number of transfers for some passengers at transfer stations, effectively decreasing the actual passenger flow through transfer stations, and relieving pressure on these stations.

(3) Shortening passengers’ travel time and improving travel efficiency. The operation of express/local trains and cross-line trains under the interconnected mode shortens passengers’ travel time to a certain extent in terms of transfer time, train stopping and starting time, etc., and improves the level of operational services.

(4) Optimizing resource allocation and improving the utilization rate of operational resources. Under the interconnected operation mode, rail trains can operate on different lines, be stationed at different depots, and drivers can operate trains on various lines. Therefore, operating enterprises break the original mode of allocating personnel, vehicles, and materials by line, as well as the limitations in the use of operational materials. Instead, they conduct overall resource arrangement based on network conditions and passenger flow distribution, thereby reducing operational costs.

In summary, the interconnected operation mode of rail transit integrates originally independent lines into a single network, realizing the feasibility of flexible operation of trains from different lines on this network and strengthening the connection between various lines. Therefore, under the interconnected operation mode, it is necessary to comprehensively consider the passenger flow characteristics of the network and line conditions to formulate a networked operation plan [7].

3.2. Disadvantages of Interconnected Operation

(1) For dispatching: Although interconnected networked operation can improve the flexibility of train operation organization, a global dispatching system

must be established to command cross-line trains and express/local trains, ensuring operational safety. Meanwhile, the formulation of cross-line train routes and express/local train operation plans must be integrated and coordinated with regular operation plans. In the event of an emergency, it will affect both cross-connected lines. Overall, the difficulty of dispatching and organization for interconnected networked operation is greater than that of single-line operation, with more new problems and challenges.

(2) For passenger transport organization: The guiding signs at cross-line stations and passing stations will be more complex, leading to an increase in the proportion of passenger inquiries and complaints, which places higher requirements on station staff.

(3) For passengers: Although cross-line routes and express/local trains can improve the directness and speed of travel, passengers need an adaptation period in the initial stage of operation, making it prone to problems such as taking the wrong train or missing their stop. At the same time, the operation of cross-line routes and express/local trains will result in longer train intervals in some sections or stations, reducing the service level for passengers in these areas.

4. Conclusion

This paper clarifies the composition of the multi-level rail transit system and conducts an in-depth analysis and summary of the concept of the interconnected operation mode, which is essentially a deep-level networked operation mode. It elaborates on the concepts, applicable scenarios, as well as the advantages of diversified operation organization, improved travel efficiency, and high utilization rate of operational resources of four interconnected operation modes: shared-line and shared-track operation, separate-line operation, cross-line operation, and connected-line operation. In the future, the development of urban rail transit in mega-cities should promote the interconnection of rail transit based on the unification of construction and operation standards for various types of rail transit, cross-regional coordinated operation mechanisms, and the improvement of policies and regulations.

Funding

2024 Guangdong Provincial University Young Innovative Talents Program (“Research on the Interconnection of Multi-mode Rail Transit Networks in the Guangdong-Hong Kong-Macao Greater Bay Area Under the Background of ‘Four-network Integration’”, 2024KQNCX213).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Yu, H.L. and Guo, C.J. (2025) Research on the Implementation Path of Integrated

-
- Development of China's Multi-Level Rail Transit. *Railway Economics Research*, No. 1, 18-25. (In Chinese)
- [2] Zhao, S.Y., Ji, Y.N., Yang, L. *et al.* (2022) Research on the Integration Modes and Selection Decision Methods of Suburban Rail Transit with Other Rail Transit Types. *Urban Rapid Rail Transit*, **35**, 106-113, 134. (In Chinese)
- [3] Wang, Y.X. (2022) Research on the Applicability of Interconnection Between Rail Transit Networks Under the Background of Multi-Network Integration. *Modern Urban Transit*, No. 9, 47-50. (In Chinese)
- [4] Yu, P., Song, W.W. and Chen, Y.W. (2022) Discussion on the Interconnection Modes and Technical Requirements of Suburban Rail Transit Under the Condition of "Four-network Integration". *Comprehensive Transportation*, **44**, 44. (In Chinese)
- [5] Ye, Y.L., Zhou, W.T., He, J.Q., *et al.* (2023) Research on the Interconnected Operation Modes of Urban Agglomeration Rail Transit Networks. *Modern Urban Transit*, No. 2, 1-6. (In Chinese)
- [6] Yu, X. and Zhang, L.Y. (2021) Research on the "Four-Network Integration" Development of Beijing's Rail Transit and Railway. *Modern Urban Transit*, No. 1, 1. (In Chinese)
- [7] Liu, Y.X., Bai, C., Zhang, W.H., *et al.* (2025) Analysis of the Connotation and Modes of Rail Transit Interconnection Under the Background of Multi-Network Integration. *Urban Rail Transit Research*, **28**, 12-18. (In Chinese)