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PROSPECT

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System and prospects of China's intercity rail transit technology

Abstract City clusters and metropolitan areas in China are flourishing in the midst of the deepening urbanization in the country, thereby resulting in the emergence of intercity rail transit. Intercity railways connect mainline and urban railways for an integrated regional transportation system that underpins and leads the development of city clusters and metropolitan areas. This study explores the development mode and service characteristics of intercity rail transit, as well as proposes overviews on this system and prospects of its future technology in China.

Keywords intercity rail transit, city cluster, technical demand, technology system

1 Introduction

The recent years saw the rapid development of urbanization in China as cities and numerous city clusters and metropolitan areas continuously emerge in the country. To enable rapid and convenient intercity travel, the comprehensive arrangement of intercity railways was proposed through the 13th Five-Year Plan of Chinese Railway. This plan calls for advancing the construction of intercity railway in developed and densely populated regions to gradually form a network. In addition, the breakthroughs of this railway construction will be applied in other appropriate regions. Government organizations are also engaged in issuing the relevant policies and standards to guide the sound development of an intercity rail transit system.

City clusters are mainly classified into three basic special forms in light of the different modes of spatial development and various levels of regional economic development. The first form is the radiation of multiple satellite cities (e.g., Changsha-Zhuzhou-Xiangtan Delta and Wuhan City circle) around large cities with closely interconnected economic activities. The second is the network type, where cities within a city cluster have a similar development performance while the city cluster is developing either in a highly concentrated manner with one center or in a decentralized manner with multiple centers. Such regions (e.g., Yangtze River and Pearl River Deltas) feature a relatively developed economy and considerably large passenger flow. The third is the corridor type, where cities are distributed at both ends or along the transportation corridor within a city cluster while such cluster is developing either around two centers or along one transportation corridor (e.g., Beijing-Tianjin-Hebei, Chengdu-Chongqing, and Jinan-Qingdao economic zones). The three types of city clusters share such common characteristics as dense population, close economic and living interactions, and large daily passenger flow. Thus, these characteristics demand a large capacity and highly efficient transportation mode to facilitate the mobility of the people.

Given the travel demand of people within a city cluster and metropolitan area, a comprehensive analysis was performed on aviation, high-speed railway, intercity and urban rail transit, and road transportation. The result showed that aviation and high-speed railway are mainly for long-distance passenger transportation and urban rail transit for transportation within cities. Similarly, road transportation is for long-distance (occasionally intercity) travel; however, this system has limited sustainability because of its reduced safety performance, convenience, speed, eco-friendliness, and capability compared with the railway. Meanwhile, intercity rail transit is the optimal solution for an integrated regional transportation and the travel of numerous passengers. The reason is that this transport system features excellent safety, rapid speed, limited environmental footprint, sustainability, high efficiency, and strong service capability. An intercity rail transit is capable of accommodating large passenger

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transportation and conducive to promoting the transformation of the regional economic development mode. Moreover, this transit system will optimize the industrial layout, spatial structure, and resource allocation, as well as improve the efficiency of land usage, thereby promoting the development of regional integration and urbanization. Accordingly, intercity rail transit will act as an absolute underpinner for rapid and punctual passenger travel in urban clusters and metropolitan areas by addressing such problems as traffic congestion, pollution, and energy shortage caused by the significant development of automobiles. In terms of function, intercity rail transit is a rapid, convenient, and large-capacity passenger rail transportation system established between core cities or within the commuting circle of one large city in developed and highly populated city clusters. Hence, intercity railway is an integral component of an integrated regional transportation system and is also built between at least two cities, thereby simultaneously shouldering a few suburban railway functions within a city. The sound development of integrated transportation entails an excellent connection and interchange between an intercity railway and other railways, roads, aviation, and other modes of transportation.

2 Service characteristics of intercity rail transit

Intercity railway operates as a bridge between the mainline and urban railways, as well as provides medium- and short-distance passenger transportation and commuting services in densely populated city clusters with developed economy. This process is typical between central cities, between a large city and its satellite cities, and between a city center and its suburban area. Travel time using an intercity rail transit is typically within 2 h, which aims to build hour economy circles.

Intercity rail transit can be divided into two types in terms of how it is constructed. One type refers to regional intercity, which is deployed for considerably long-distance travel of over 100 km between major cities, as well as between a large city and its satellite cities within one city cluster. The other type is called metropolitan commuting intercity or suburban intercity, which is adopted for considerably short distance travel within 100 km between the center of a large city and its suburban areas or satellite cities. As the application varies, the regional and suburban intercities are different in such aspects as service object, passenger flow characteristics, service level, operational organization, and speed level. Table 1 shows the specific comparison between regional and suburban intercities.

The preceding comparison shows that an intercity rail transit is constructed differently based on the specific conditions of the city cluster and metropolitan area where this system is located. Overall, intercity rail transit is characterized by large passenger flow, limited headway, limited distant stations, and short travel time, as well as mainly undertakes medium- and short-distance passenger transportation for trading, schooling, and commuting. Intercity railway acts as a bridge for integrated regional transportation; hence, this system is required to connect the mainline and urban railways. Consequently, this process plays an indispensable role for door-to-door service.

The characteristics of intercity rail transit service are finalized to reflect transportation demand. From the transportation locality perspective, the arrangement of intercity lines and passenger service characteristics are from the local features related to the form of a city cluster and the extent that different cities within a city cluster interact with one another in life, work, and economic activities. From the operation mode perspective, intercity rail transit features a large passenger flow, numerous stations, and frequent boarding and disembarking, thereby entailing a bus-mode service in high-density and short compositions. From the transportation approach perspective, the multiple stopping modes are available with the differentiated station distances, such as point-to-point, all-station, and trans-station stoppings. From the service application perspective, intercity rail transit boasts of 24-h and all-weather operation features, which are unique features of rail transportation. From the service demand perspective, people who travel using intercity rail transit require an improved service, enhanced riding comfort, and

Table 1 Comparison between regional and suburban intercities

Characteristics	Regional intercity (typically over 100 km)	Suburban intercity (typically below 100 km)
Scope of application	Between major cities in one city cluster	Between big city and its satellite cities
Service object	Intercity commuting and business travel of medium distance	Intercity trading, schooling, and commuting of short distance
Passenger flow	Evident tidal phenomenon	Substantially prominent tidal phenomenon and transportation in city centers
Service level	One-way travel time of under 2 h	Entire travel time of approximately 1 h; focuses on convenience
Operational organization	With multiple operation modes; operating on main lines or dedicated intercity lines to build hour economy circles in city clusters	To build hour economy circle by intercity lines and suburban lines, bus-mode operation supplemented by trans-station and point-to-point stopping modes
Speed level	160–200 km/h	120–160 km/h

easy information exchange and acquisition (i.e., via Wi-Fi or telephone). From the service capability perspective, patronage to intercity rail transit is distributed in the form of a “dumbbell,” which means a limited number of passengers in the middle and many at both ends. Therefore, flexible service is required with an adjustable dispatching frequency to meet with the actual passenger flow by considering such tidal passenger flow as vacations, holidays, and morning and evening peak hours. From the compatibility perspective, intercity rail transit is highly compatible with the higher speed railways and larger capacity urban railways given that the former enjoys a wide speed range from 120 to 200 km/h.

3 Technical requirements of intercity rail transit

The comprehensive analysis of the functions and service characteristics of intercity rail transit shows that this transportation method combines the high speed and continuous operation features of a mainline railway with the large capacity, rapid start-up and stop, and rapid boarding and disembarking features of an urban rail transit. Given such characteristics, this study includes detailed research to identify the technical requirements of intercity travel.

The highest service speed of intercity rail transit is up to 200 km/h. The capability to operate at high speed is required given that intercity trains are applicable to point-to-point, all-station, and trans-station stoppings.

To cope with passenger flow during peak hours, intercity trains are designed with flexible composition. The gangway, coupler, and high-voltage connection at the car ends can be immediately coupled and uncoupled. The network is provided with a friend-foe identification function. Traction, braking, and auxiliary systems are of small module design to minimize the impact of composition changing.

For the short station distance operation, a traction system with large torsion, bogie brake system with large thermal capacity, and brake control system with automatic load adjustment function are required for rapid start-up and stopping.

For the short headway operation, numerous doors with large opening width, wide corridor, and vestibule are required for the immediate boarding and disembarking of passengers.

High-strength and lightweight aluminum alloy car body is deployed in addition to the lightweight bogie adaptable to the wide loading range, high voltage alternating current with large capacity, and interior layout combining seats and standing space. Thus, a train is able to accommodate numerous passengers.

A variety of propulsion modes, such as driven by new energy or electricity of different voltages via pantograph-catenary, third rail, or other approaches, should be provided to ensure the applicability to the mainline and urban railways, as well as realize the integrated regional rail transportation.

Intercity rail transit is required to be substantially competitive in such aspects as waste emissions, noise pollution, and energy utilization for sustainable development.

Given the specific technological requirements of intercity rail transit projects, a variety of intercity transit modes are available to meet such demand, which mainly includes traditional wheel rail transit vehicles, medium- and low-speed maglev trains, and monorail trains. At present, traditional wheel rail transit vehicles are still the mainstream in the development of intercity rail transit system in China, whereas other rail transit systems serve as complementary systems. They could contribute to the building of intercity rail transit systems. The following section focuses on the discussion of traditional wheel rail transit system.

4 System of the intercity rail transit technology

The system of intercity rail transit technology has yet to be established. To illustrate, guiding industrial policies are absent, technical standards should be further regulated, planning theory system is incomplete, and planning method and mode are immature. Therefore, the technology system of intercity rail transit shall be identified based on the current status and future development planning in this field. The principles to be observed are recommended as follows.

Building a complete hierarchy structure of China’s rail transit as the orientation: To determine the specific functional requirements of intercity rail transit in accordance with the positioning and functional demands of the China’s rail transit at different levels, thereby integrating the three networks of mainline, intercity, and urban railways.

Regulating the industrial technical standard system as the target: To establish a regulated standard system for intercity rail transit, thereby supporting the preparation of industry development policy and guidance for the healthy and sustainable development of the intercity railway sector.

Overall consideration of technical advancement, adaptability, and value-for-money: To consider technical advancement, adaptability, and value-for-money based on the development tendency of the global intercity rail transit and demand for new intercity railways in China.

Focus on status quo and future development: To consider the status quo and future development of intercity rail transit technology to identify the technical system, thereby ensuring the sustainability of this rail transit system.

Interoperability principle: To confirm the feasibility of interconnectivity between the existing intercity railways and other types of railways on the premise of a three-network integration, thereby maximizing the efficiency of the integrated rail transportation.

Conservation and environmental protection: To focus on resource conservation and environmental protection, increase the efficiency of land usage, and establish a resource conserving and eco-friendly transportation mode.

The technical systems of infrastructure and transport tools substantially contribute in establishing the technical system of an intercity rail transit. Accordingly, these two technologies are inseparable. Interconnectivity shall be considered to reduce passenger travel time and increase travel speed.

4.1 Interconnectivity

Interconnectivity is an inevitable trend for future rail transit, and the pattern of interconnectivity for such rail transit system should be reasonably selected based on regional differences, thereby balancing future development and the present situation.

The following provision for this new type of railway transportation system is explicitly defined in the Code for Design of Intercity Railway (TB10623-2014), that is, an intercity railway can be operated independently on its own system. The interconnection with other railway networks or interchanges should be considered at major stations. The starting and intermediate stations should be connected with the urban railways for convenient interchange service. This principle will enable interconnectivity to be gradually and systematically realized, particularly through the following two technical routes.

The first route entails interconnecting with a mainline railway, thereby boosting the unified standard system. The seamless connection with the mainline railway will enable us to maximize its resources and provide additional space for future development. Moreover, an interchange service is required for an urban rail transit to achieve interconnectivity. However, the constraints of a substantially large gauge and high one-off input cost make it suitable for cities on the main corridor, as well as metropolitan areas with a developed economy, large urban city, and large intercity network.

The other route entails interconnecting with an urban rail transit, thereby boosting the diversified standards for transit gauge, signal system, and other systems. Furthermore, interconnectivity is only realized through an interchange service. The standards for metro construction can be adopted to achieve interconnection with specific metro lines, as well as realize interconnection with other metro lines and mainlines via the stations. This method is considered suitable for suburban intercity with a relatively small population density and limited scale of urbanization, or the commuting intercity within the metropolitan area of large cities with well-established metro networks.

Therefore, projecting the national long-term development has convinced us that the interconnection of a mainline railway and urban rail station is the mainstream for future intercity rail transit. The reason is that this process will provide substantial opportunities for the development of an intercity railway.

4.2 Gauge standards

Gauge standards for intercity rail transit are crucial for the future development of this industry. Two technical routes are involved. One route is the standard for mainline railway, which is unified with a mature system, such as GB146.1 and GB146.2. Although this method can meet the requirement of interconnectivity, such route requires a considerably high input cost due to the large gauge. The other route is the standard for urban rail transit, which should be re-established due to various systems for urban rail transit that lack a unified specification, various gauge signals, and speed level under 120 km/h.

The interconnection requirements can be completely achieved by adopting the GB146 gauge, which is also applicable to urban rail vehicles with outstanding compatibility. If the urban rail gauge is selected, then trains with substantially large sections are inaccessible. In addition, adopting the GB146 gauge standard for the unified gauge section can ensure an improved interface between the vehicle and platform, as well as narrow the platform gap. This standard can also deal with the matching of the speed level to form a complete standard system, as well as solve the problem related to signal system unification to avoid multiple signals.

A comprehensive analysis of the current situation of intercity railway development will result in the adoption of the mature GB146 series standard for future mainstream intercity railway line. This scenario will maximize the dynamic envelope calculation and aerodynamic technologies, thereby reducing tunnel area and investment cost. In a few places with appropriate regional scale or the commuting intercity where the urban rail transit network is well-built, an intercity rail transit can establish individual standards based on the gauge of an urban rail transit.

4.3 Driving power

The status and function of an intercity rail transit and its various application conditions are crucial for the diversified power patterns of mobile equipment. Accordingly, these factors will satisfy the application of the mainline AC25kV and consider the possibility that underdeveloped areas may use a non-electrified line network. In addition, it should consider the electromagnetic performance of the city-center-passing areas, safe distance for discharging, and the resulting matters related to investment that may demand for the DC1500V.

A comprehensive analysis indicates three main modes. The first mode is the train traveling through the regional main corridor of the mainstream and municipal intercities of large cities in non-center-passing areas. This mode is advisable with the AC25kV. The second mode is the intercity train running on electrified and non-electrified blended railways. This mode is advisable with the AC25kV, diesel, and new energy driving. The third mode is the commuting train in the metropolitan area of underdeveloped cities or commuting train on center-passing lines and in the metropolitan area within the intercity network. This mode is advisable with the DC1500V or 750V, or the hybrid power of the AC25kV + DC1500V (DC750V).

The future mobile equipment for an intercity rail transit should be equipped with multiple power modes based on the diversified driving power modes to adapt to the systematic design of the lines. The intercity rail transit in our country has just begun unlike in Japan and Europe. Moreover, no historical problems have restricted these places. In Japan, the municipal area and existing mainlines adopt the narrow gauge and DC1500V for power supply. The standard gauge and the AC25kV power supply are adopted in the Japanese Shinkansen. In Europe, the standard rail is prioritized with diversified forms of power supply systems, such as AC15kV, AC25kV, DC1.5kV, and DC3kV. Evidently, line differences cannot be denied and interconnection can only be realized by the subsequent diversification of vehicles. Therefore, historical experience and lessons should be drawn from these countries, with unified planning and systematic implementation, as well as the unified construction of standards.

4.4 Speed level

The Intercity Railway Design Specification (TB10623-2014) indicates that the line speed level for a newly built intercity railway, where only EMUs are running, should be from 200, 160, to 120 km/h. Given the situation of the existing lines where intercity EMUs start to operate, as well as multiple factors (e.g., line conditions of the intercity rail transit, stop distance, travel speed, traction energy consumption, and various application modes, such as point-point, all-station, and trans-station stops), a mobile equipment should be equipped with a variety of speed levels to meet the application demand. We should conduct a comprehensive consideration of acceleration and deceleration distance, travel speed, energy consumption, as well as provide full play to the traction performance. Speed is closely correlated with the average station stop distance (see Table 2 for the details).

China has formulated plans for intercity rail transit projects, and the distance between stations is in the 5–10 km range. Given the different operation modes (e.g., all-station and major station stops) and the fact that an urban rail transit covers the speed range of 80–120 km/h, the speed level of a mobile equipment of an intercity rail transit is recommended in the range of 120–200 km/h, rated as 200, 160, 140, and 120 km/h.

Table 2 Speed and average station stop distance

Average station stop distance/km	Appropriately selected speed level /($km \cdot h^{-1}$)
⩽3	100–120
⩽5	120–140
5–10	160
⩾10	200

4.5 Formation types

Intercity rail transit is characterized by large passenger and tidal passenger flows, with unbalanced development between regions, and considerable differences in passenger flow in the recent medium and long-term periods. Therefore, to form a systematized mobile equipment, the diversified ratios of the motor and trailer cars, as well as the composition type based on the traffic situation in different regions and different periods, should be reasonably configured.

An intercity rail transit vehicle has three forms of power configuration. The first form is a 2-motor car and 1-trailer car as a unit, which can realize the 3-car, 6-car, and 9-car formations. The second form is the 1-motor car and 1-trailer car, which can realize the 4-car, 6-car, and 8-car formations. The third form is a type of flexible formation with a self-contained transformer and convertor in the motor car. Hence, this formation is free from the constraints of a fixed number of motor or trailer cars, as well as makes flexible and dynamic formations constantly available.

The EMU formations are recommended to be subject to actual application requirements. In particular, EMUs with fixed unit of motor and trailer cars should be equipped with a coupling function to achieve substantially long or short configuration. EMUs with flexible configuration should not be equipped with a coupling function to achieve either a considerably long or short configuration via the immediate configuration of vehicle number.

4.6 Train control system

Train control system is a type of modern technical equipment that ensures the safety of train operations, improves the capability of passing through the interval and station, and increases the economic benefit of railway transportation.

The establishment of a standard system for a train control system, selection of technical route, and determination of performance requirements should be implemented by significantly considering the characteristics of an intercity rail transit, drawing mature application experience from the existing mainline railway and signal system of the urban rail transit. This process will enable them to adapt to and meet the requirements of the intercity rail transportation, as well as maximize the benefit of investment.

Through comprehensive analysis of the existing train control technology and future development tendencies, the lines of the 200-km level are recommended to adopt the train control system of CTCS-2 and CTCS-0 levels, as well as add the ATO function if required. Lines of the 160-km level or below should adopt the train control system of the CTCS-0 level, as well as add the ATO function if required. A few lines that interconnect with the urban rail transit should adopt the ATC and CBTC systems, which are consistent with the standard of urban rail transit.

4.7 Comprehensive riding comfort

The passenger travel distance undertaken by an intercity rail transit transport is between the mainline railway and urban rail transit. Moreover, general comfort should be attributed to the excellent match between travel time and economic performance. The related indices, such as vehicle noise, air quality, pressure fluctuation, and sitting space, should be above those of the urban rail transit vehicle and below those of the mainline railway vehicle. The general comfort index can be determined based on the application practices of previous projects.

5 Development trend of intercity rail transit

To realize the healthy development of an intercity rail transit technology system, the service characteristics and technical requirements should be given considerable attention. We should engage in common technology, such as material application, vibration noise and structural strength, advanced technologies (e.g., passive safety design, driverless operation, online diagnosis, and repair and maintenance), and application technologies (e.g., clean energy and carbon fiber) to raise the service level of intercity rail transit and substantially satisfy the traveling needs of the people.

To meet the demand of a large passenger loading, the lightweight bearing structure should be realized through the lightweight design and application of new materials, thereby achieving the largest passenger loading capacity.

To satisfy the integration demand of the regional transportation, multi-mode driving and multi-mode train control technologies should be adopted to regionally integrate the mainline, branch line, intercity, and urban rail transit.

To improve transport efficiency, traction transmission and train control technologies, among others, should be improved.

To upgrade the environmental protection performance, measures should be taken from new materials, new energy, and other aspects.

To achieve rapid development, the planning and construction of an intercity railway should be led by the provincial government under the macro control of the national governing department. Construction through PPP, BOT, BT, and other modes can also be explored together with the gradual introduction of social capital.

6 Conclusions

Intercity rail transit technology system and its development cannot be independent from the planning and guidance of the governing department. Therefore, we explicitly defined the governing department for planning and construction, as well as prepared an industry guidance to immediately promote the development of intercity rail transit. In addition, we should establish a standard system of design and the construction and operational technology consistent with the features of intercity railway, guide local regions to actively and steadily push the planning and construction of intercity rail transit, and provide support for its healthy development.

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