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Exploration on Engineering Management Practice of China’s High Speed Railways

Abstract This paper explores the principal motivations and successful experiences of the rapid development of China’s high speed railway. In the perspective of the engineering management practice, the developers have studied and made prospective mid- and long-term railway network planning, including the four east-west and four north-south corridors as the backbone, the interregional urban passenger traffic corridors and the intercity railways, with a planning scale above 16,000km. Under the overall coordination of the government, a high speed railway technology system has been formed with the China’s characteristics, by the way of sticking to independent innovation, of combining original innovation, collaborative innovation and integrative innovation, and of attaching importance to experimental verification. The target control system and support-guarantee system were established for the high speed railway project, enacting standardized management, strengthening integration test and commissioning, conducting strict acceptance, and achieving construction management experiences on the high speed railway. Finally, this paper proposes such issues worthy of attention and further study, as the improvement of the engineering decision-making management, the enhancement of investment and financing system reform, and the promotion of professionalization and the specialization of engineering project management.

Keywords: high speed railway, engineering management, practice, innovation

1 Introduction

High speed railway (hereinafter referred to as HSR), a collection of high and new technologies, is an important symbol of railway passenger traffic modernization, with the distinct characteristics of the contemporary times, making the traditional railway display great vitality. At the beginning of 21st century, the Chinese Government formally incorporated HSR into The mid- and long-term railway network program and took a series of effective measures to promote it actively.

Generally, the operating speed is the critical factor to define HSR. In Japan, the trunk line with an operating speed above 200km/h is called HSR (Shinkansen). The International Union of Railways calls the newly built railway with an operating speed above 250km/h and the existing railway with an operating speed above 200km/h as HSRs. And in China, HSR refers to the newly built passenger dedicated line (The Ministry of Railways, 2013a) designed for the electric multiple units (hereinafter referred to as EMUs) with an operating speed of 250km/h (including that with the condition reserved for further upgrade) and above, and with an initial operating speed not less than 200km/h.

Based on the advanced experiences of HSR construction of the world, China has gradually set up the technology system of HSRs, by sticking to the independent innovation, and through practices as building the quasi-high speed railway and passenger dedicated lines and speeding up the existing railway lines, which provides reliable technical supports for the development of HSR.

Through years’ efforts, China has made great achievements in design, construction, equipment manufacturing, operation management and other aspects for HSR, with the operational mileage breaking through 10,000km, whose overall technology is among the most advanced in the world. This paper explores the principal motivations and successful experiences of the rapid development of HSR and proposes some opinions and suggestions on the management improvement, based on the engineering management practices of China’s HSRs.

2 The planning management of China’s railway networks

2.1 Study on railway network planning

Rapid passenger traffic is the trend of China’s railway devel-
In 2000, when studying and preparing “The Tenth Five-Year Plan”, the former Ministry of Railways launched the study on the development planning for 2020. The study on HSR network planning elaborates mainly on the following issues: the separation of passenger transport from freight transport on the busy trunk line with a limited capacity, the development of the intercity railways in the densely-populated regions with well-developed economy, and the strengthening of the construction of the passenger corridor systems between major economic zones. It makes the HSR networks coordinate and connect with other modes of transport and play a key role in the comprehensive passenger transport network, so as to meet the demand of the national economic and social development.

The total scale of China’s HSR network was calculated with the network analysis method, transport demand method and international analogy method, and the HSR arrangement was designed with the actual plotting method. According to the study, the passenger transport centers of the railway network as Beijing, Shanghai, Guangzhou, Wuhan, Chengdu and Xi’an, and the regional railway passenger traffic centers as the extra large cities and provincial capital cities with a population above 1 million, can well serve as the major points of linkage for interregional HSRs.

The mid- and long-term railway network program, deliberated and approved by the State Council in 2004, describes a grand blueprint of the railway development in the first 20 years of 21st century. According to the implementation status of this program, the State Council adjusted the total scale and layout of China’s railway network and proposed a higher planning target and requirements (The Economic and Planning Research Institute of the Ministry of Railways, 2007; The National Development and Reform Commission, 2004).

### 2.2 Characteristics of the planning

#### 2.2.1 Large construction scale and high standard

For the scale of the newly built HSRs (including the intercity railway), the planned mileage was above 12,000km in 2004, and was adjusted to 16,000km in 2008. The main railway trunk lines were to be built according to a speed level of 300–350km/h, and the railway trunk lines mainly for passenger transport and also for freight transport were to be built according to a speed level of 200–250km/h. The HSR development planning with such a large scale and high standard is unique in the world.

#### 2.2.2 To highlight the four east-west and four north-south corridors

In accordance with the theory of the grand transport corridor, the main passenger transport corridors with the characteristics of high transport strength, long distance and wide collection and radiation range, play a decisive framing role in the railway passenger transport network. Also based on the theory, the study determined the four east-west and four north-south corridors as the backbone of China’s HSR network (see Figure 1), in combination with the main passenger flow distribution in the central cities and between regions.

The four north-south corridors are as follows: The Beijing—Shanghai HSR (with a full length of 1,318km) links up the Circum-Bohai Sea, the Yangtze River Delta and the

![Figure 1. The four north-south and four east-west corridor network.](image-url)
The Operational Mileage of China’s HSRs

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Mileage in 2008 (km)</th>
<th>Mileage in 2009 (km)</th>
<th>Mileage in 2010 (km)</th>
<th>Mileage in 2011 (km)</th>
<th>Mileage in 2012 (km)</th>
<th>Mileage in 2013 (km)</th>
<th>Total mileage (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300–350</td>
<td>118</td>
<td>1,079</td>
<td>1,050</td>
<td>1,318</td>
<td>2,254</td>
<td>924</td>
<td>6,743</td>
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<tr>
<td>200–250</td>
<td>149</td>
<td>1,293</td>
<td>955</td>
<td>356</td>
<td>200</td>
<td>833</td>
<td>3,786</td>
</tr>
<tr>
<td>Total</td>
<td>267</td>
<td>2,372</td>
<td>2,005</td>
<td>1,674</td>
<td>2,454</td>
<td>1,757</td>
<td>10,529</td>
</tr>
</tbody>
</table>
studied. According to the requirements on intensifying the comprehensive transport network for the new situation of the national economic and social development and the new type of urbanization planning, the total scale of the HSR network further studied may exceed 20,000km. In addition to the backbones of the HSRs, the railway network layout needs to be added with new interregional fast corridors. To further optimize and improve the eastern city agglomerations, cultivate and develop the central and western city agglomerations, it is also necessary to add HSRs between some city agglomerations and the internal intercity railways of the city agglomerations.

3 Technological innovation management

The guiding thoughts for the independent innovation for China’s HSRs are valuing self-reliance, learning from all of strong points, aiming at first-class level, seizing upon late-move advantages and employing “corner overtaking” strategies, so as to open up a new road for the development of China’s HSRs (Sun, 2009).

3.1 The history of the technological innovation and development

The study on China’s HSR technologies has experienced a course of more than 20 years, which could be divided into five stages roughly as the following.

3.1.1 The stage for preparation of the basic technology (late 1980s—1993)

In this stage, while tracking the technological development of the world’s HSRs, the study on the basic technology was carried out. In 1993, some relevant institutions of China completed The preliminary study on major technical and economic issues of the Beijing—Shanghai HSR, which made the preliminary technological preparations for the development of HSRs. The study report pointed out that China needs to develop HSR, and also has the ability to build HSR.

3.1.2 The stage for study of the engineering technology (1994—1997)

In 1995, the former Ministry of Railways founded the Beijing—Shanghai HSR Construction Office, whose responsibilities were to organize technical exchanges, tackle scientific and technological problems and also scientific experiments, and carry out a comprehensive study on major technologies of HSRs. In 1997, the “Pre-feasibility study on the Beijing—Shanghai HSR” was finished and then The project proposal for the newly built Beijing—Shanghai HSR was submitted to the State. The Beijing—Shanghai HSR was listed as one of the major national construction projects.

3.1.3 The stage for in-depth study of technology (1998—2002)

This stage was focused on repetitive demonstrations on the wheel-rail technology system and the maglev (magnetic levitation) technology system. And the former Ministry of Railways upheld to use the wheel-rail technology system on the Beijing—Shanghai HSR. The major technological issues of the HSR were further studied, and then the results were preferably applied to the construction of the new passenger dedicated lines and the speeding-up projects of the existing lines. Practices proved that the key technologies of the HSR were gradually approaching maturity through continuous improvement.

3.1.4 The breakthrough stage for the major technologies (2003—2007)

In 2007, the operating speed of China-made “China Railways High-speed (CRH)” high speed EMUs reached 200–250km/h on the upgraded lines of the existing railways, based on the successive breakthroughs on the major technologies such as track works, traction power supply and communication signals. By drawing up the Interim provisions on design of the Beijing—Shanghai HSR and through international consultations on the design scheme of the Beijing—Shanghai HSR, the interim provisions on the design of 300–350km/h HSR were further worked out, and the technology system of China’s HSRs was initially formed.

3.1.5 The stage to realize the leap-forward development (2008—now)

A batch of 250km/h and 350km/h HSRs were put into operation. Through operation practices on the long and large trunk lines, safety, comfort, advancement and economy of China’s HSR technology were verified. The maximum test speed of the independently developed “CRH” EMUs (CRH380A) reached 416.6km/h on the Shanghai—Hangzhou HSR on Oct. 26, 2010, and reached 486.1km/h on the Beijing—Shanghai HSR on Dec. 3, 2010, which created a new record of HSRs in the world. China has entered the new era of HSR construction since then.

3.2 The mode of technological innovation

To achieve the railway development strategies, efforts were concentrated on the key technological issues of HSRs, patterning the mode of technological innovation “guided by the government, driven by the market, conducted by enterprises, with cooperation of industries, universities and research academies”.

3.2.1 The overall industrial plan

Through playing a guiding role of the government, the for-
The former Ministry of Railways developed the development strategies and technological policies of HSRs, and used the market mechanism to encourage the enterprises to carry out technological innovation. By coordinating and integrating the resources, advantages have been formed of the market, the capital and unification, achieving the technological innovation at high starting points and avoiding low-level and repetitive researches and developing efforts.

3.2.2 The collaborative innovation

Enterprises serve as the subjects of the technological innovation, capital investment and risk bearing, and also the beneficiary subjects of the achievements. The enterprises are expected to establish the dynamic collaborative alliances with the relevant scientific research institutions, colleges and universities, overcome the technical difficulties with the alliances, and yield breakthroughs in technological innovation.

3.2.3 The integrative innovation

HSR construction is a complex and huge systematic engineering. All the sub-systems within are not only self-contained but also co-related, and must rely on the system integration technology to ensure integrity and coordination, and to achieve the unit and interface innovation of the integration technology, as well as the system integration innovation.

3.2.4 The introductive innovation

Some of the core technologies of the HSR system beyond China’s present ability of independent research and development in China, are to be introduced in accordance with the principle of “advancement, maturity, economy, applicability and reliability” at first, and then, through digestion and absorption, developed with re-innovation. The introduction of high speed EMU technology has the most typical significance. In 2004, the State set the principle of “building up China’s brands, by the introduction of the advanced technologies, and joint designing and manufacturing”. The former Ministry of Railways integrated the resources, performed competitive purchases among the domestic manufacturers, definitely set the principles of foreign enterprises working only as the domestic enterprises’ partners, and promised to transfer core technologies and implement gradual localization of technologies. After successfully introducing the 250km/h EMU technology, it organized researchers to digest and absorb, realizing the technological re-innovation and the independent design and manufacture of the 350km/h and 380km/h EMUs.

3.2.5 The experimental verification

Most of the newly built HSR projects were provided with the engineering test sections for systematic field researches. The tests were carried out successively in the Kunshan soft soil subgrade test section of the Beijing—Shanghai HSR, the ballastless track test section of the Suining—Chongqing HSR, the integrated test section of the Wuhan—Guangzhou HSR, the collapsible loess test section of the Zhengzhou—Xi’an HSR, and the expansive soil engineering test section of the Hefei—Nanjing railway. The important achievements of the field engineering tests optimized the contents of technological innovation, and laid a solid foundation for popularization and application. On the circular test track in the eastern suburbs of Beijing, the Qinhuangdao—Shenyang passenger dedicated line and all the newly built HSR lines, the actual operating EMUs or test trains were employed to carry out comprehensive tests on the state, performance, functioning and mutual coordination for all the systems and make adjustment, which optimizes the overall performance and provides the reliable basis for safe and stable operation.

3.3 Building of the technological system

The technological system of China’s HSR includes such major components as fixed equipment, mobile equipment, train operation control system, and operation management system (see Figure 2).

Facing the challenges of the vast territory, the large environmental difference and high requirements of the various regions of China, the HSR technology has been continuously improved through practices. The key technologies of the engineering construction were tackled on the complicated geological conditions such as soft soil, collapsible loess, expansive soil, frozen soil and karst, and the weather conditions with a minimum temperature of −40°C and a maximum temperature of 47°C, as well as the environmental impacts of sand, wind and seawater. For example, the subgrade and foundation treatment, post-construction settlement control within 15mm, the large-span bridge of new structure, tunnels with long and large cross section, design and construction of

Figure 2. The structure diagram of China’s HSR technology system.
underwater tunnels, large-scale simply supported girder and the complete technology of ballastless track, all above ensure high regularity and stability of the lines.

The independently developed “CRH” high speed EMUs came up with all around innovations in the streamlined head, highly air tight body, high speed bogie without bolster, traction system with great power, high-performance braking system, train intelligence and other aspects. The large tension and full compensation chain type suspension of high strength copper alloy contact wire was developed, establishing the integrated automation system of the traction power supply (SCADA). The Level CTCS-3 train control system, based on global system for mobile communications for railway (GSM-R), was developed to realize the bi-directional real time transmission of train control information between the ground and the EMUs, and the decentralized self-discipline centralized traffic control system (CTC) was employed to realize the centralized control of signal equipment and the direct command of train operation. The testing technology of infrastructures, the early warning technology of disasters, and advanced comprehensive testing train were developed, establishing the emergency rescue system. The overall design, interface management, coordination and cooperation were strengthened, the joint commissioning and testing technology was innovated, and the system integration technology was upgraded.

A 2011 investigation concerning 1,147 technical equipment of enterprises engaged in HSR construction, conducted by the related departments of the former Ministry of Railways indicated that, the equipment independently developed in China accounted for 80% approximately. Except the EMUs that were mainly developed with introductive innovation, the equipment of all other domains was achievements of original innovation and integrative innovation. For example, original innovation contributed 75.9% of the track works, and 81.6% of the traction power supply field. In future, the emphasis of scientific research work is to be concentrated on the development of such core technologies and equipment as EMUs, train controlling, and ballastless track, according to China standards.

The improved HSR technology system promoted the formulation of the technological standards of the HSR products, the standardization of engineering construction and operation technologies, and further formed the standard technological system of China’s HSR with proprietary intellectual property rights, and laid a foundation for the execution of the strategy of China’s HSR “going abroad”.

4 The engineering project management

In the construction of HSRs, the successful experiences of Qinghai—Tibet Railway engineering management were popularized and applied, the construction idea was updated, the systems of such domains as management organization, objective control and support-guarantee were improved, and effective operation mechanism was established, and all of these measures worked well to achieve good effects in the project management.

4.1 Regulating of the construction procedures and management subjects

The construction procedures of a large-scale engineering project are mainly divided into 4 stages: project approval and decision-making, survey and design, project implementation, and completion acceptance. As the operational duration of the HSR projects is not long, the project’s post-completion evaluation will be arranged later (see Figure 3).

The work of HSR projects in different stages was completed by different responsible entities. The work in project approval and decision-making, engineering design and completion acceptance stages was mainly organized by the related departments of the former Ministry of Railways. After entering the implementation stage, a project joint stock company funded by multiple parties was fully responsible for the construction and operation of the project. A railway administration or a railway investment company, as the investor’s representative of the former Ministry of Railways, local government investment institutions, and enterprises or financial institutions would make the investment. It was required that the capital fund of the company should not be lower than 50%
of the total project estimate, and the remaining construction fund was mainly from direct financing such as railroad bonds issued by the former Ministry of Railways, and indirect financing such as loans granted to the project legal person by banks or non-bank institutions. The project company should implement the management mode of “small enterprise and big consultation”, and set lean and effective working organizations. During construction, the project company could employ professional companies to provide technical and management consultation services for the project. When the project was put into operation, the project company might independently bear or entrust the railway administration to which it was affiliated to be responsible for operation management and maintenance work.

4.2 Optimizing of the project decision-making and engineering design

The project decision-making of HSR mainly includes railway development planning, project proposal and project feasibility study report. For the proposed HSR project, bidding on design should be carried out, and the design institute winning the bidding should undertake the project pre-feasibility study and prepare the project proposal. Once the project proposal was approved, the detailed feasibility study should be carried out to deeply analyze and fully demonstrate the technical advanced applicability, economic benefit rationality, and construction feasibility of the project. The project feasibility study report was an important basis for the project approval and decision-making.

The design of HSR projects was carried out in two stages, i.e. preliminary design and construction drawing design. A technical design stage (the expanded preliminary design) might be added for special projects according to the practical conditions. The design institute should prepare the preliminary design documents with the location survey data according to the approved project feasibility study report. It was mainly the study of the principles and scheme of the engineering design, as well as major technical issues, proposed the quantities of works, resource demands, construction organization design and total estimate, and evaluated the economic benefits, social benefits, environmental impact, and the existing risks of the project. The preliminary design reviewed and approved by the former Ministry of Railways would be used as the basis to control the total scale and total estimate of the project. The preliminary design must meet the need of engineering bidding, material purchasing, land acquisition and relocation, and construction preparations. As most of the construction contractors did not have the ability to undertake the construction drawing design, the work was generally still prepared after supplementing the location survey data by the design institute. The employer (owner) should entrust the consultation entity to review the construction drawing, and then submit it to the construction contractor for implementation.

4.3 Implementing of the dynamic management and effective control

4.3.1 Establishing of the objective management system

The HSR project construction generally adopted the design-bid-build (DBB) mode, with the active exploration of engineering procurement construction (EPC) mode, partnering mode and other modes. The project management organization should implement the thoughts of man-centered development and sustainable development, and establish the overall objectives of the project, including “the five controls” of construction quality, environmental protection, occupational health and safety, construction period, and investment, which is a significant development of the traditional project management. The objectives should be decomposed respectively according to the project types, construction contractors, construction years, etc., so as to form a whole-course covering, mutually correlated and coordinated objective management system. The dynamic control should be carried out through strengthening information collection, analysis and research during the whole process of the project implementation in order to ensure the completion of the overall objective.

Exploration was undertaken based on the new mode of “quality, environmental protection, health and safety integrated management” (QEHS). Adhering to the principles of objective management, prevention first and resource share, the quality management system standard ISO9000, the environmental management system standard ISO14000, and the safety and health system standard OHSAS18000 were integrated into a comprehensive management system, which simultaneously could meet the requirements of the above three standards, and meanwhile, management files were prepared and review was organized, contributing to enhance the management efficiency and level of the engineering project.

4.3.2 Establishing of the support-guarantee system

In order to facilitate the achievement of the overall objective, measures were taken to strengthen the management of the project contracts, risks, resources, information, culture, technology innovation, etc., and to establish an information management platform based on geographic information system (GIS), building information model (BIM) and other technologies, so as to cover project management elements, arrange reasonably construction organization plan, optimize resource allocation concerning manpower, materials, equipment and capital, and implement dynamic adjustment and controlling, providing support and guarantee for the objectives of “the five controls”.

4.3.3 Conducting of the standardization management

In the implementation stage, standardization management was conducted, with emphasis on the standardization of management system, personnel arrangement, site manage-
ment and process controlling. Special emphasis was placed on strengthening basic work, establishing and improving technological standards, management systems and personnel training systems. Meanwhile, measures were taken to intensify process control, implement fine management, and intensify external supervision efforts while implementing strict internal control for enterprise. Efforts were made to perform strict check and accept, establish reward and punishment mechanism, and encourage enterprises to fully meet the objective requirements.

4.4 Implementing of completion acceptance and safety assessment

Upon the completion of an engineering project, the owner would carry out the professional acceptance, then the former Ministry of Railways would organize the preliminary acceptance, and related national departments would organize a formal acceptance after the operation of more than one year. For the preliminary acceptance, the static acceptance was organized, checking the integrity and accuracy of the project data, entity quality and environmental impact, etc., so as to determine whether the project reached the acceptance standard of the professional industry or not. And then the dynamic acceptance was conducted, with routine tests applied on track state, power supply and transformation, communications, signals, passenger service system, and special tests on subgrade, transitional sections, track structures, turnouts, bridges, tunnels, noise vibrations, electromagnetic compatibility, disaster prevention and safety monitoring. Take the geometrical state of track as an example. According to the test results of the high speed test train, the assessment would be made for the local amplitude and section quality, as shown in Table 2 (The Ministry of Railways, 2013b), indicating the management value of the allowable deviation in the local amplitude evaluation.

Before putting into operation, a HSR project would be subject to safety assessment organized by the former Ministry of Railways. The safety assessment would aim at an all-around check and analysis on the possible safety risks according to the laws and regulations, and the technological standards of safety management, including equipment and facilities, operational institutions, departments and personnel, environmental impacts, emergency plans, etc. And the safety assessment report was an important basis for the allowance of putting into operation.

5 Conclusions

For the development of China’s HSR, efforts were taken to formulate The mid- and long-term railway network program, to conduct the innovative management with professional industrial characteristics, and to explore the engineering project management in different regions, which totally contributed to the success of China’s HSR. However, there are still some issues worthy of attention and further in-depth study, for the sake of the continuous improvement of engineering management.

It is necessary to further improve the management system and support methodology of the decision-making, placing enough emphasis on the risk management in the decision-making, and the preliminary work of project construction. And it is of importance to regulating the behaviors of decision-making agents, implanting the thoughts of comprehensive benefits and mutual interests, strengthening total life span management, and establishing decision feedback and accountability systems to prevent mistakes in project decisions.

The railway investment and financing system must proceed with radical change and renewal. It is necessary to classify construction projects, with the profit-making railway projects primarily financed by the market and the non-profit railway projects constructed by the government. It is of vital importance to improving the formation mechanism of the railway transport rate and non-profit transport compensation mechanism, constructing a transparent transport clearing mechanism, setting up the railway development fund, implementing the preferential fiscal and tax policies, and promoting high-quality railway projects to be listed, so as to attract capitals from the society for railway construction.

There is the need for the professionalization and specialization of railway engineering project management. It is necessary to abandon the practice setting up temporary

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The Acceptance Management Value of the Allowable Deviation of Track State in Amplitude Evaluation</th>
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<tbody>
<tr>
<td>Track speed level</td>
<td>250km/h</td>
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<tr>
<td>Deviation class</td>
<td>Class I</td>
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<td>Track gauge (mm)</td>
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<tr>
<td>Horizontal (mm)</td>
<td>4</td>
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<tr>
<td>Distortion (mm) (gauge length: 3m)</td>
<td>—</td>
</tr>
<tr>
<td>Vertical (mm) (wavelength: 1.5–42m)</td>
<td>4</td>
</tr>
<tr>
<td>Rail alignment (mm) (wavelength: 1.5–42m)</td>
<td>4</td>
</tr>
<tr>
<td>Vertical acceleration of car body (m/s²)</td>
<td>—</td>
</tr>
<tr>
<td>Horizontal acceleration of car body (m/s²)</td>
<td>—</td>
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</tbody>
</table>
management agencies based on projects, and instead, build construction, supervision and consultation institutions with qualifications and competitive competencies according to the market planning. And meanwhile, it is important to improve enterprise management quality, construct effective coordination and cooperation mechanisms, motivation and restraint mechanisms and performance evaluation mechanisms, so as to meet the urgent demand of the modernization of engineering project management.

References


