INTERNATIONAL DEVELOPMENT IN FOCUS

China's High-Speed Rail Development

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Foreword

2018 marked the 40th anniversary of China's "reform and opening up"—a period of high growth and poverty reduction. China's remarkable development was made possible by a wide range of reforms that transformed the economy into a more market-based open economy and through a large-scale infrastructure development program.

China's leadership in transport development started with years of investment in skills and know-how, focused on quality, safety, timely completion, investment benefit, environmental protection, and technical innovation. China has made fantastic progress in developing its transport infrastructure. From 1990 to today, China has added over 120,000 kilometers (km) of railways, 130,000 km of expressways, 3.7 million km of road, and 740,000 km of coastal quay lines to its national transport system.

The World Bank has been China's partner in this journey. In the past three decades, the World Bank has approved more than 110 transportation projects in China, with a total investment of $19 billion. The World Bank has also been a knowledge partner, producing over 15 targeted studies captured in the China Transport Topics series. The World Bank and China's Ministry of Transport have jointly developed the Transport Transformation and Innovation Knowledge Platform (TransFORM) program—a flagship knowledge platform to share Chinese and international transport experiences and facilitate learning within China and other World Bank client countries.

What can other countries learn from China's success? Chinese best practices are very relevant for World Bank clients looking for sustainable solutions to transport development challenges. Through TransFORM, the World Bank is analyzing China's experience in five areas of transport—high-speed rail, highways, urban transport, ports, and inland waterways—to identify lessons that are transferrable from China to other developing countries. This report on high-speed rail is the first in this series.

The report covers a broad range of why, what, and how questions. Since 2008, China has put into operation a high-speed rail network that is larger than all the high-speed networks in the rest of the world put together. This rapid growth makes China worth studying from the "how" perspective: What planning processes, capacity development, business structures, and construction modalities enabled this rapid growth? China's traffic has grown to 1.7 billion passenger trips per year. In an era when many railways face declining patronage, what price and service characteristics make high-speed rail attractive to this large number of passengers? China was the first middle-income country to develop a high-speed railway network and to price the service so that people of all income levels use high-speed rail. Why can China price high-speed rail services affordably and still maintain financial and economic viability?

I encourage you to read the full report to find the answers to these and many other questions.

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About the Authors

Richard Bullock has over 40 years of experience in the railway sector, covering costing and pricing, project analysis, railway restructuring, and regulatory issues. He has worked on over 50 railways worldwide, in every continent except North America, and has worked in China since 1987. Before becoming an independent consultant, Mr. Bullock was a director of Travers Morgan Australia and, in addition to the World Bank, has worked on projects for several other international institutions. He has worked on seven high-speed rail projects in China with the World Bank, as well as five outside China.

Mr. Bullock has an MA in mathematics from Cambridge University and an MA in operational research from Brunel University.

Martha Lawrence is the leader of the Railways Community of Practice at the World Bank and a team leader for the World Bank's technical assistance and lending programs in China and India. She has over 30 years of experience in the railway sector, with extensive knowledge in railway restructuring, railway finance, and transport regulation. Ms. Lawrence led the development of the World Bank's resource on railway reform, *Railway Reform: A Toolkit for Improving Rail Sector Performance*, and the report *Attracting Capital for Rail Development in China*. She has prepared business, restructuring, and financing plans for railways worldwide and advised private sector investors on over US$8 billion in structured lease financing of transit rolling stock and infrastructure.

Ms. Lawrence has a BA in economics from Northwestern University and an MBA in finance and transportation management from Northwestern University.

Ziming Liu joined the World Bank in 2017 as a transport consultant in the Beijing office. She has been involved in the World Bank's technical assistance and lending programs in China and Central Asia in the transport sector since then. She has contributed to multiple World Bank studies, including the upcoming flagship report *Innovative China: New Drivers of Growth*, the study on land-based transport in Europe-Asia trade, and other studies on China transport and logistics.

Before joining the World Bank, Ms. Liu worked as a student research assistant at the University of Pennsylvania and the University of Hong Kong. She applied advanced geographic information system techniques and big data analysis to urban economics and geography research in an innovative way.

Ms. Liu's current interests are railways, freight and logistics, transport economics, and mega infrastructure projects.

She has a BEng in civil engineering from the University of Hong Kong and a master's degree in city planning from the University of Pennsylvania.

Abbreviations

CRC	China Railway Corporation
CRCC	China Railway Construction Corporation Ltd.
CREC	China Railway Group Ltd.
CRH	China Rail Highspeed
EIRR	economic internal rate of return
EMU	electric multiple unit (trainset)
FIRR	financial internal rate of return
FYP	Five-Year Plan
GDP	gross domestic product
GHG	greenhouse gas
HSR	high-speed rail
JV	joint venture
km	kilometer
kph	kilometer per hour
kWh	kilowatt-hour
MLTRP	Medium- and Long-Term Railway Plan
MOR	Ministry of Railways
MOT	Ministry of Transport
NDRC	National Development and Reform Commission
NRA	National Railway Administration
PDL	passenger dedicated line
pkm	passenger-kilometer
RA	Regional Administration
SASAC	State-Owned Assets Supervision and Administration Commission
VOSL	Value of Statistical Life
VOT	value of time
Y	Chinese yuan

Executive Summary

Since 2008 China has put into operation over 25,000 kilometers (km) of dedicated high-speed railway (HSR) lines, far more than the total high-speed lines operating in the rest of the world. The World Bank has provided financing for some 2,600 km of these lines, beginning in 2006. Since then, the World Bank has evaluated and monitored seven projects, five of which are already in service. This report builds on a report prepared by China Railway Design Corporation, together with analysis and experience gained during the World Bank's work. It summarizes China's experience with HSR and presents key lessons for other countries that may be considering high-speed rail investments.

China was the first country with a gross domestic product (GDP) per capita below US$7,000 to invest in developing an HSR network. China is unique in many ways, including size (9.6 million km^2); long distances between North and South, and East and West; the current stage in its economic development (GDP of US$7,590 per capita in 2017); and substantial population density (141 people per km^2).[1] China has many large cities with population greater than 500,000, located at distances (between 200 and 500 km) that are well suited for HSR.

In 2008 the first fully HSR line in China was opened, between Beijing and Tianjin, coinciding with the 2008 Beijing Olympic Games. Since then, China has opened 25,162 km of high-speed lines (as of end-2017) with design speeds ranging from 200 to 350 km per hour (kph). It is by far the largest passenger-dedicated HSR network in the world and currently operates over 2,600 pairs of China Rail Highspeed (CRH)[2] trains each day.

The high-speed services represent a radical change in the provision of passenger services by China Railways. Not only have travel times been markedly reduced, but capacity has also significantly expanded. For the first time, passengers on most HSR routes can now "turn up and go," except at peak periods. Over 10 years, the CRH service has carried over 7 billion high-speed passengers, second only to the 11 billion carried by the Japanese Shinkansen over the past 50 years. CRH currently carries 56 percent of the 8.3 million passengers using the China nonurban rail network each day.

The current level of demand, at 1.7 billion passengers per year, confirms the strong need for such service along core corridors and the willingness of many to pay substantially higher fares than charged for conventional intercity trains. The total annual volume carried is already far larger than on the French TGV services and the Japanese Shinkansen services. It will continue to grow rapidly as the many lines under construction are completed and as urban incomes and population in China continue to rise. Traffic on conventional rail services has continued to grow despite diversion to high-speed services, but at a very slow pace (0.5 percent per year). Compared with other leading countries with HSR services, China has achieved a strong start with good traffic densities at an early stage of implementation.

A broad range of travelers of different income levels select the HSR for its short travel time, comfort, convenience, safety, and punctuality. It facilitates labor mobility, family visits, tourism, and expansion of social networks. Nearly half of the passengers travel for business purposes.

By offering a new service quality at a very different price point, China has broadened the range of intercity options, enabling a better matching of supply and demand. This has freed up considerable capacity on conventional trains, on which tickets were formerly very difficult to secure, for lower-income groups who are more price sensitive.

During the past decade, China has accumulated considerable experience in planning, constructing, and operating high-speed lines. This report summarizes key lessons from this experience that may be applicable in other countries.

The first chapter outlines the background to the development of HSR in China and the key role played by the Medium- and Long-Term Railway Plan (MLTRP). This plan, first approved in 2004 with revisions in 2008 and 2016, looks up to 15 years ahead and is complemented by a series of Five-Year Plans, prepared as part of the general planning cycle. These plans are rarely changed once approved. The initial Medium and Long Term Development Plan planned for an HSR network of 12,000 km by 2020. The 2016 revision is now aiming for a network of 30,000 km by 2020, 38,000 km by 2025, and 45,000 km by 2030 (NDRC 2016). The development of a well-analyzed long-term plan, strongly supported by government, provides a clear framework for development of the system.

The lines have been constructed from the start through special-purpose asset construction and management companies. These companies are normally joint ventures between the central and provincial governments. This structure secures the active participation of local government in planning and financing the projects. Cooperation among rail manufacturers, universities, research institutions, laboratories, and engineering centers enables capacity development, rapid technological advancement, and localization of technology.

The second chapter discusses the key choices in service design. Service frequency must balance operating cost and use of line capacity with attractiveness to potential passengers. Most HSR lines have at least an hourly service between 7:00 a.m. and midnight. This level of service requires an average load of 4 million to 6 million passengers per year throughout its route to be operated efficiently. On most lines, the China Railway Corporation (CRC) operates a mixture of express and stopping services. Few services stop at all intermediate stations. The choice of service frequency is matched to the volume of passengers using the station. Line speed is determined by balancing the line's role in the network, market demand, and engineering conditions with investment cost.

Fares are competitive with bus and airfares. Chinese HSR fares are low compared to other countries, which enables HSR to attract passengers from all income groups.

The third chapter analyzes the market for HSR. It gives examples of HSR's ability to attract passengers from other modes (including conventional rail). In corridors in China, HSR typically captures up to half of the conventional rail traffic, most of the intercity bus traffic (except for short distances), and a large share of air traffic up to 800 km. In China, HSR also generates 10–20 percent new trips that were not previously made by any mode.[3] Although half of the trips are made for business purposes, the low fares enable HSR to attract passengers for all trip purposes and from all income groups.

The fourth chapter describes the procedures China has adopted when constructing new lines. One of the most striking lessons for other countries is the speed with which public sector organizations can build high-quality infrastructure when given clear guidance and responsibilities. The Chinese HSR network has been built at an average cost of $17 million to $21 million per km—about two-thirds of the cost in other countries—even though many Chinese lines have a high proportion of their route on viaducts or in tunnels.

Although labor costs are lower in China, a key factor in the lower cost and rapid and efficient HSR construction has been the standardization of designs and procedures. The steady stream of projects has also encouraged the creation of a capable, competitive supply industry. The large HSR investment program, which does not change once approved, has also encouraged the development of innovative and competitive capacity for equipment manufacture and construction and the ability to amortize the capital cost of construction equipment over multiple projects.

HSR project managers have clear responsibilities and delegated authority to carry them out. They typically stay for the full duration of the project, ensuring a clear chain of responsibility for the implementation of the project. Their compensation includes a significant component of incentive compensation related to performance.

The fifth chapter discusses the procedures China has adopted when commissioning new lines and its approach to ensuring operational safety. China manages safety risks throughout the project life cycle by assuring appropriate technology in the design phase, quality construction in the building phase, and thorough inspection and maintenance in the operational phase.

To ensure safe operation, China collects asset condition data through a mix of physical inspection and dynamic testing with instrumented equipment. These data are analyzed centrally to identify maintenance requirements. During operation, a test train is run at the start of each day's operations to check the infrastructure. An instrumented train is run every 10 days to check condition. A four-hour window is provided every night for maintenance.

The sixth chapter explains the financing of the system. As might be expected, the financial picture varies from line to line. Heavily used 350 kph lines with average traffic densities of more than 40 million passengers per year and average revenue per passenger-kilometer (pkm) of Y 0.50 (US$0.074) are able to generate enough ticket revenue to pay for train operations, maintenance, and debt service.

In contrast, many lines in China with traffic density of 10 million to 15 million passengers per year, especially 250 kph lines with average pkm revenue of Y 0.28 (US$0.041), can barely cover train operations and maintenance, and will be unable to contribute toward their debt service costs for many years. These results should not be interpreted as demonstrating that a 350 kph line is inherently more financially viable than a comparable 250 kph line. The main reason for the disparity in financial viability is the pricing policy that has been adopted in China. This issue has been recognized, and greater pricing flexibility is now being allowed.

Options to improve cost coverage for loss-making lines include (i) increasing fares for 250 kph lines where traffic demand permits, (ii) increasing nonfare revenue, and (iii) providing government subsidy. Financial restructuring actions include (i) grouping feeder lines with main lines to pool revenues and costs and (ii) reprofiling principle repayments to shift payments to later years when traffic volumes are greater. Overall, the financial rate of return for the network as it was at end-2015 is estimated at 6 percent,[4] a return on par with the cost of financing of CRC.[5]

The seventh chapter discusses the economic impact of the HSR services. These services provide major benefits to users in terms of reduced travel time, increased service frequencies, greater availability of seats, and improved comfort.

Economic benefits also accrue from reductions in operating cost as users of higher-cost modes such as automobile and air transfer to HSR. These transfers also generally reduce externalities (accidents, highway congestion, and greenhouse gases).[6] Benefits also derive from the deferral of the need to invest in expanding the capacity of other modes as a result of demand transferring to HSR.

Other economic benefits are associated with improved regional connectivity. HSR can contribute to rebalancing growth geographically to reduce poverty and enhance inclusiveness.

Overall, the economic results appear positive, even at this early stage. The economic rate of return of the network as it was in 2015 is estimated at 8 percent, well above the opportunity cost of capital adopted in China and most other countries for such major long-term infrastructure investments. There is thus a reason to be optimistic about the long-term economic viability of the major trunk railways of the HSR program in China.

How much of this experience is replicable and potentially instructive for other countries considering investment in HSR? Potential lessons and replicable practices include

- A well-analyzed Long-Term Plan, supported by government, with minimal changes once approved;
- Standardization of designs;
- Competitive supply industry;
- Partnering with local government;
- Project management structure with clear responsibilities and decision-making authority, managers who stay for the duration of the project, and significant incentive compensation for managers;
- Safety system that identifies and manages risk during all project phases;
- Service with high punctuality, frequency, and speed;
- Value of good connectivity with conventional rail and urban transport;
- High-volume, medium-distance markets;
- Pricing that is affordable and competitive with other modes, and finds the "sweet spot" that maximizes revenue while not substantially discouraging ridership; and
- Offering a range of services (high speed and conventional) at different price points to meet different passenger needs.

NOTES

1. The Central and Eastern Provinces are particularly dense, with average population of 420 people per km^2, about the same as the Netherlands.
2. In this report, HSR refers to the high-speed network—that is, lines on which services can travel at over 200 kph. This network includes both the dedicated new passenger lines with a design speed of 200 kph or above and the new passenger-freight lines with a maximum design speed of 200 kph. CRH refers to the train services that operate over these lines; some of these trains also continue on upgraded conventional lines. A similar situation occurs in France, where the TGV trains operate on both the high-speed network (LGV) and connecting sections of the conventional network.
3. The generation of new traffic is discussed in chapter 3 in the section titled "New Traffic."
4. Assuming inflation of 2 percent per year.
5. Assuming inflation of 2 percent per year.
6. However, GHG savings during operation need to be balanced against GHG generated during construction, either directly or through the GHG embedded in construction materials such as cement and steel.

REFERENCE

NDRC (National Development and Reform Commission). 2016. "Mid- and Long-Term Railway Network Plan." National Development and Reform Commission of the People's Republic of China, Beijing.