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# High-Speed Railways in China: A Look at Construction Costs

**Gerald Ollivier, Jitendra Sondhi and Nanyan Zhou**

**World Bank Office, Beijing**

*By the end of 2013, China Railway had built a network of about 10,000 route-km of high-speed railways (HSR). The network has been built rapidly and at a relatively low unit cost compared with similar projects in other countries. This note takes a look at this expansion, its construction unit costs and some of its key cost components. It also outlines reasons that may explain the comparatively low cost of HSR construction in China.*

## Introduction

In terms of HSR length, China now leads the world. The HSR program started in 2003 with a 404 km line between Qinhuangdao and Shenyang operated at a maximum speed of 250 km/h. It rapidly gained momentum (Figure 1) with the Mid-to-Long Term Railway Network Plan adopted in 2004, and updated in 2008, which laid out the railway development plan through 2020. The Beijing–Tianjin HSR, the first of a new generation of HSR, opened in August 2008 with a maximum speed of 350 km/h.

## HSR in China

Definitions of HSR differ but, generally, railways with a maximum speed of 250 km/h or more are considered as HSR (UIC, 2008). According to Order No. 34, 2013 from China's Ministry of Railways, HSR refers to newly built passenger dedicated lines with (actual or reserved) speed of 250 km/h and above. By 2013, China had completed construction of a high-speed rail network of about 10,000 route-km. China's HSR network now far exceeds the HSR network in any other country and is larger than the HSR network in the entire European Union. It will continue to grow as more than 12,000 route-km HSR are currently under construction in China[1]. In addition, China has built a number of new 200 km/h express passenger railways and 200 km/h mixed use railways. This note covers both the HSR and new 200 km/h speed railways in China.[2]

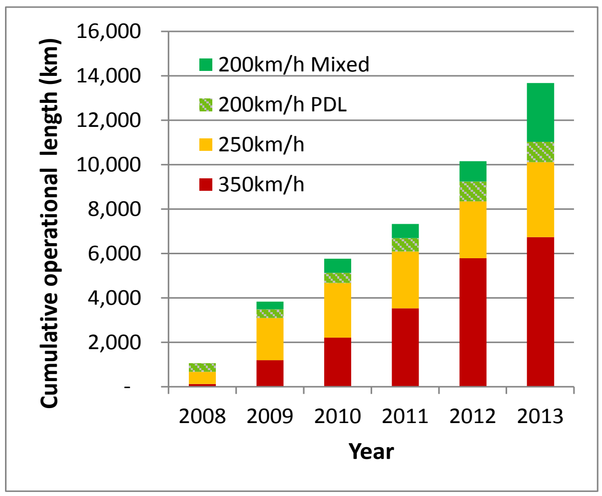



**Figure 1. Length of China HSR and 200 km/h lines by year by category 2008-2013. Source: Yearbooks of China Transportation & Communications, China Railway Yearbooks, and Planning & Statistics Department of CRC**

In China, HSR lines on high density corridors such as Beijing-Shanghai and Beijing-Guangzhou tend to have a maximum design speed of 350 km/h. HSR corridors with more modest volumes of passengers have a maximum design speed of 250 km/h. Generally, both of these types of HSR are passenger-dedicated lines (PDL) and are newly built as green-field projects.

[1] Xinhua News, Mar 05, 2014. see: http://news.xinhuanet.com/fortune/2014-03/05/c_119626642.htm

[2] A further 6,000km or so of existing conventional rail lines were upgraded to 200 km/h as part of the sixth acceleration in 2007, although the information about such upgraded lines is not detailed enough to be reported here.

At the end of December 2013, most of the metropolitan regions in China are either connected, or in the process of being connected, to lines with a maximum speed of 200 km/h or above. The map on the next page shows the HSR routes that are operational, under construction, or in the CRC's current plan[3].

All HSRs and 200 km/h speed trains are operated with Electric Multiple Unit trains (EMU) consisting of 8 or 16 carriages. Based on current CRC train schedules (2014), 70 to 100 pairs of HSR trains are operated daily on busy routes and up to eight pairs of trains per hour are operated during peak hours. Traffic density on such routes is estimated at about 20-30 million passengers[4]. On medium density routes, 40 to 50 pairs of trains are operated daily. Two types of services are provided. Express trains stop only at major cities while other trains also stop at intermediate stations.

Based on the People's Railway Post in January 2014, the average seat occupancy is 70 percent. Second class fares of HSR vary between US$ 0.045 per km at 200 to 250 km/h and 0.077 at 300 to 350 km/h. This is three to four times that on conventional express trains, but this is lower or comparable to discounted air fares and, at the lower end, similar to intercity bus fares. This is about one fourth or one fifth of the fares applied in other HSR countries[5]. These trains provide world-class quality of service and comfort. They have carried a large volume of passengers safely, except for one major accident in 2011 that caused about 40 fatalities[6], attributed to inadequate testing of a new design of signaling equipment, which lacked proper fail-safe features.

**Cost of HSR Lines**

An analysis of the cost for 27 HSRs in operation[7] at the end of 2013 showed the unit cost varied substantially. The unit cost of 350 km/h projects was between RMB 94-183m per km (Figure 3; see also section below on Cost Factors). The unit cost of 250 km/h PDLs was, with a couple of exceptions, between RMB 70-169m per km. The weighted average unit cost for a line[8] was RMB 129m per km for a 350 km/h project and RMB 87m per km for a 250 km/h project.

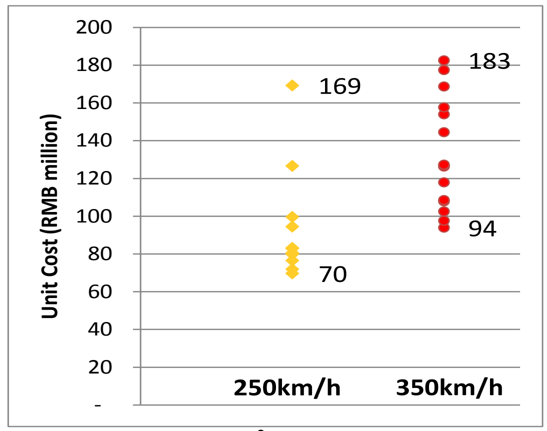



**Figure 3. Unit Cost of PDL[9] (Based on Estimated cost at the time of Project Approval) Source: Year books of China Transportation & Communications 2007-2013/China Railway Yearbooks**

These costs provide a general indication of construction cost levels but this data is only available in aggregate form at this point. Expenditures were incurred over different years, so costs may not be directly comparable[10], given the impact of inflation as well as fluctuations in the supply and demand for rail construction services. But they nonetheless provide a useful range of benchmarking values for new projects.

[3] This map includes projects as listed in China Transportation and Communications Year Books (2007 to 2013). Commencement of civil works signifies the beginning of construction although land acquisition precedes beginning of construction.

[4] Wu, *The Financial and Economic Assessment Investments: a Preliminary Analysis. Passenger density is defined as total passenger km per year on a route divided by route length.*

[5] France: 0.24 to 0.31 US$/km; Germany 0.34 US$/km; Japan: 0.29-0.31 US$/km, based on official travel websites.

[6] Germany had an accident in 1998, resulting in 101 fatalities. Spain had an accident in 2013 resulting in 79 fatalities. Japan, in its long history of HSR operation, has never had a fatality due to a HSR train accident.

[7] Cost data sourced from official publications of China Railway Corporation and former Ministry of Railways.

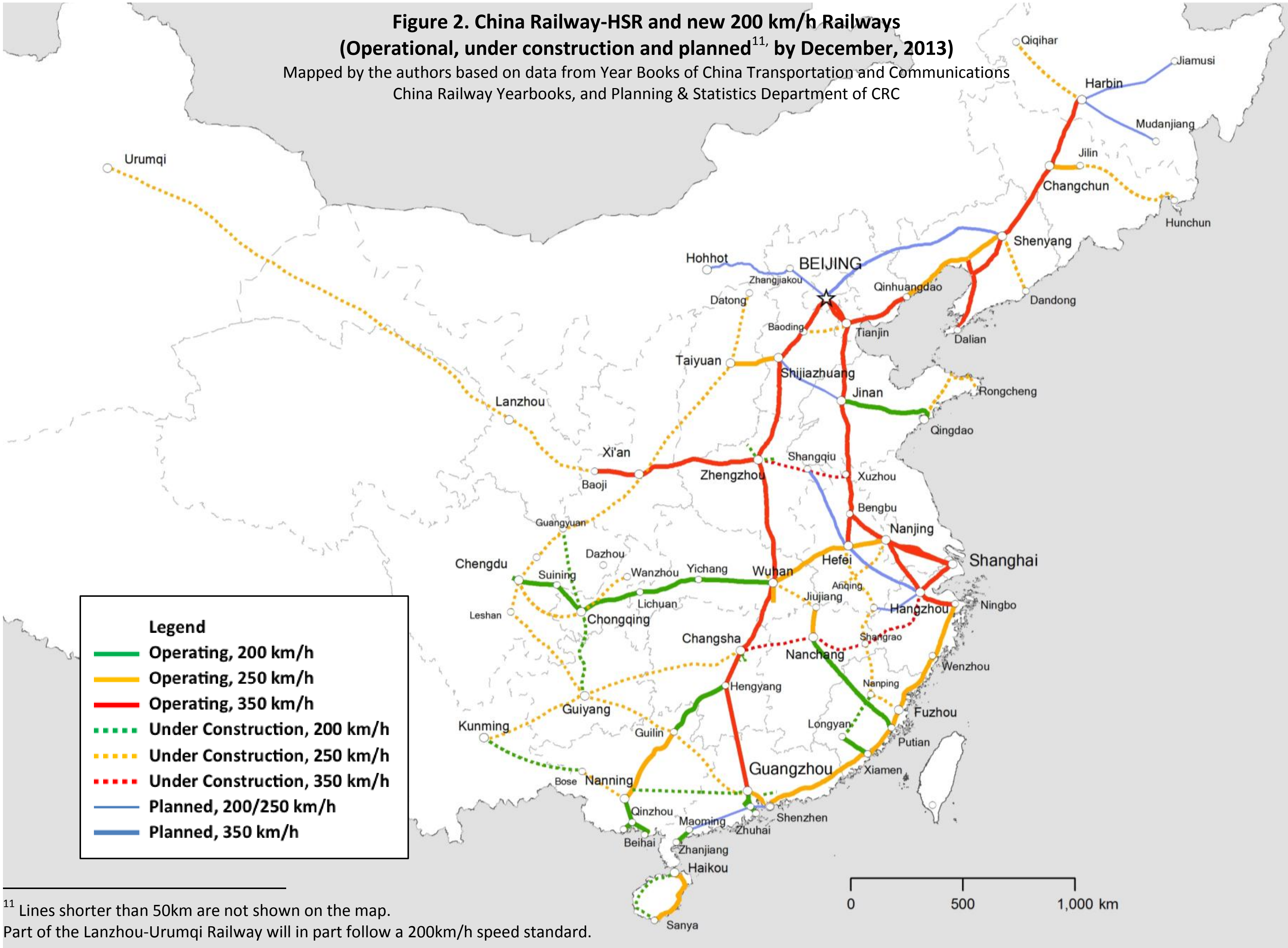
[8] Includes cost of project preparation, land, civil works, track works, core systems, regular stations (but only some of the mega stations), depot and yards, rolling stock and interest during construction.

[9] The unit cost for a new 250km/h would be higher as most of such lines were completed by 2010.

[10] 250 km/h lines were built about 2 years earlier.

**Figure 2. China Railway-HSR and new 200 km/h Railways (Operational, under construction and planned[11], by December, 2013)**

Mapped by the authors based on data from Year Books of China Transportation and Communications China Railway Yearbooks, and Planning & Statistics Department of CRC




[11] Lines shorter than 50km are not shown on the map.
Part of the Lanzhou-Urumqi Railway will in part follow a 200km/h speed standard.

**HSR Projects Supported by the World Bank in China**

The main features of railway projects which have been supported by World Bank are summarized in Table 1. Since 2006, the World Bank has provided financial and technical support for six railway projects with speeds of 200 km/h or above. One of these, the Shijiazhuang-Zhengzhou HSR project, which is part of the Beijing-Guangzhou HSR, was completed and commissioned in December 2012, while the others are at different stages of implementation.

Table 2 shows the contribution of various elements to the total project cost for all Bank-supported projects. Civil works contribute about 50 percent of the cost while signaling and communications and electrification each contribute about 5 percent of the cost. Table 3 shows the average estimated unit cost of some elements of railway projects supported by the Bank. Information gathered during project supervision indicates that actual costs are close to the estimated costs. An analysis of the actual cost of building the Shijiazhuang-Wuhan PDL (841 km), which included the Shijiazhuang-Zhengzhou Railway, indicates that the actual unit cost was about 5 percent below estimates.

**Table 1. Railway Projects Supported by the World Bank in China**

| Project | Max. Speed kph/Type | Length Km | Total Estimated Cost RMB b | Unit Cost RMB m/km | Bridges+ Viaduct+ Tunnels (% of route km) | Period of Construction |
|---|---|---|---|---|---|---|
| **Shijiazhuang - Zhengzhou** | 350 PDL | 355 | 43.9 | 123 | 69 | 2008-2012 |
| **Guiyang - Guangzhou** | 250 PDL | 857 | 94.6 | 110 | 80 | 2008-2014 |
| **Jilin- Hunchun** | 250 PDL | 360 | 39.6 | 110 | 66 | 2010-2014 |
| **Zhangjiakou – Hohhot** | 250 PDL | 286 | 34.6 | 121 | 67 | 2013-2017 |
| **Nanning – Guangzhou** | 200 Mixed | 463 | 41.0 | 89 | 53 | 2008-2014 |
| **Harbin – Jiamusi** | 200 Mixed | 343 | 33.9 | 99 | 48 | 2014-2017 |

Notes: *1. Total project cost includes the cost of project preparation, land acquisition, construction of the railway and regular stations, contingencies, rolling stock and interest during construction. The cost of railway excluding cost of project preparation, rolling stock and interest during construction is estimated at about 82 percent of the total cost.*

*2. Cost References: GG-Revised FSR Dec. 2010, NG- PAD May 2009, Shi-Zheng PAD May 2008, Jituhun-PAD 2011, Zhang-Hu-FSR, HaJia-Revised Feasibility Study Oct.2012/PAD.*

**Table 2. Percentage of Total Project Costs**

| Element | 350 km/h | 250 km/h | 200 km/h |
|---|---|---|---|
| Land acquisition and resettlement | 4 | 4-8 | 6-9 |
| Civil works | 48 | 50-54 | 44-51 |
| *Embankment* | *6* | *7-12* | *13-15* |
| *Bridges/Viaducts* [12] | *41** | *13-25* | *25-27* |
| *Tunnels* | *0** | *16-29* | *2-13* |
| Track | 9 | 9-11 | 6-7 |
| Signaling and communications | 4 | 3 | 4 |
| Electrification | 5 | 4-5 | 4-5 |
| Rolling stock | 15 | 3-4 | 5-7 |
| Buildings including stations | 2 | 2-4 | 3-5 |
| Other costs | Balance | Balance | Balance |

*An exception is Shizheng Railway that has 69 percent of track on viaduct accounting for 41 percent of cost and no tunnels.

[12] The unit cost of bridges/viaducts includes that for short/medium length bridges over water and specially designed bridges over large rivers as well as viaducts built over dry land.

**Table 3. Range of Average Unit Costs**
(RMB million/per km of double track)

| Element | 350 km/h | 250 km/h | 200 km/h |
|---|---|---|---|
| Land acquisition and resettlement | 4 | 5-9 | 5-8 |
| Civil Works | 57 | 56-62 | 42-43 |
| *Embankment* | *24* | *31-42* | *23-28* |
| *Bridges/viaducts* | *71* | *57-73* | *59-62* |
| *Tunnels* | -- | *60-95* | *51-68* |
| Track | | | |
| *Track (ballast-less)** | 10 | 10-13 | |
| *Track (ballasted)** | | | 5-7 |
| Signaling and Communications | 5 | 3 | 3-4 |
| Electrification | 6 | 4-5 | 4 |

*Ballast-less slab track is used for 350 and 250 km/h PDLs while ballasted track is employed for 200 km/h railways.
Source: FSR/PAD for projects

**Cost Factors**

Several factors influence the cost of a HSR and 200 km/h railway project construction. The major factors include the line design speed, type of tracks, topography along the alignment[13], weather conditions (such as very low temperature requiring special design features for the road bed), land acquisition costs (these are high in dense urban areas), use of viaducts instead of embankments, the construction of major bridges across wide rivers, and the construction of mega stations.

For example, the Beijing-Tianjin HSR unit cost was higher than usual at RMB 183m per km since it included the cost of two mega stations built at Beijing South and Tianjin, which serve other lines as well. The unit cost of Shanghai-Hangzhou HSR (RMB 177m/km) was high since it included several major bridges and a high cost of land acquisition and resettlement as it traverses densely populated areas of Eastern China with high land values. Laying track on viaducts, even if more expensive than embankment, is often preferred[14] in China to minimize resettlement and the use of fertile land as well as to reduce environmental impacts.

This note looks in more detail at the cost of viaducts and bridges as experienced under World Bank supported projects and at the cost of stations.

***Low Cost Viaduct Construction***

In the projects supported by the World Bank, the estimated cost of viaducts in China ranges from RMB 57 to 73 m/km for a double track line[15]. Such costs are kept low through standardization of the design and manufacturing process for casting and laying bridge beams on viaducts. The span of viaduct beams has been standardized at 24 and 32m (weighing about 750-800t). Bridge beams are cast in temporary facilities established along the railway alignment. Each beam is transported over a distance up to 8 km by a special beam carrier vehicle (having as many as 18 axles) (Picture 1) and is launched over the viaduct columns by specially designed equipment (Picture 2). The cost of a 32m-bridge beam is about RMB 0.8-1.0 m. The slab track is also cast in temporary facilities established along the railway

**Picture 1. Beam Carrier**

[13] In particular, mountainous areas require extensive tunneling and bridge construction, which can reach as high as 80 percent of the alignment length.

[14] Three very long over-land bridges (viaducts) are part of the Beijing-Shanghai HSR which commenced operation in 2011. These are: the 164 km long Danyang–Kunshan Grand Bridge, the 114 km long Tianjin Grand Bridge and the 48 km long Beijing Grand Bridge – the first, second, and fifth longest in the world respectively at the time. Shi-Zheng Railway has 69 percent of track on viaducts to minimize land take resettlement in the fertile plains it traverses.

[15] The actual cost of a typical viaduct on the ShiZheng Railway was RMB 60-70m per km.

**Picture 2. Beam Launching Equipment**

alignment. After project completion, the bridge beam and slab track casting facilities are dismantled and reinstalled at another site. The vacated land is systematically restored by relaying the site with the original top soil and is handed over to its owners for agricultural use.

***High Cost of Unique Bridges***

Special bridges that cross large navigable rivers (class three and up) or that need to accommodate special topographic features like mountains have a cost per kilometer that can be much higher than that of a regular viaduct. Those bridges are designed to address unique challenges, and require much more intensive design work and sophisticated construction techniques. Usually such bridges represent a small percentage of the total number of bridges. Projects having larger proportion of special bridges will tend to have a high unit cost, like the Xijiang and Sixianjiao bridges under World Bank supported projects (Picture 3 and 4).

**Picture 3. Xijiang River Bridge near Zhaoqing**

*Arch suspension bridge with a main span of 450m over the Xi river and a total length of 618 m. Cost: RMB 580 million. Unit cost: RMB 938 million/km.*

**Picture 4. Sixianjiao Bridge**

*Cable-stayed steel truss bridge with 105 m high pylons. Total length of 567m. Estimated cost of RMB 490 million. Unit cost of RMB 864 million per km. (credit to Guiguang Co.)*

**Railway Stations**

Railway stations play a dual role as transport hubs and urban centers. Many of them are urban landmarks that seek to reflect the local culture and heritage, while supporting urban expansion. Traffic volumes vary widely across stations. Accordingly the size and cost of stations varies markedly with small stations (3,000 sq m station building) costing about RMB 40 million, while mega stations, more akin to airport terminals, may cost up to RMB 13 billion. The cost of regular stations, other than mega stations, is generally included in the project cost and is of the order of 1.0 to 1.5 percent of the total project cost[16]. The mega stations are frequently built as independent projects and their costs are not always included in the HSR project cost.

Mega stations are traditionally built in the largest cities, and tend to be large airport-type buildings, with close attention to architecture and local culture. Hence, Beijing South Station is reminiscent of the Temple of Heaven[17]; and

[16] The cost of 16 new stations on Guiguang Railway (250 km/h ) is estimated at RMB 1.16 billion, i.e. 1.2 percent of the total project cost.

[17] http://zh.wikipedia.org/wiki/%E5%8C%97%E4%BA%AC%E5%8D%97%E7%AB%99

Wuhan Station resembles a bird spreading its wings, inspired by the Yellow Crane, the symbol of Wuhan City[18].

Mega stations are large and expensive to build, but they fill up rapidly during peak travel period. Such stations have three to five levels and provide interchange facilities between railway, road and metro systems. The mega station at Shanghai Hongqiao has interchange facilities for the airport and for a future maglev train. These stations seek to provide facilities that promote quick and comfortable transit for large volumes of traffic. Notable among these are stations at Beijing South (RMB 6.3b-US$ 1.0b; 310,000 sq m), Wuhan (RMB 4.1b US$ 0.70b; 114,000 sq m), Guangzhou South (RMB 13b US$2.1b; 486,000 sq m) and Zhengzhou East (RMB 9.5b US$1.5b; 412,000 sq m)[19].

**Picture 5. Beijing South Station**

*(Artist's impression of station design)*

**Potential Factors Explaining Relatively Low HSR Costs In China**

HSR construction costs in China tend to be lower than in other countries. Based on experience with World Bank supported projects, the cost of railway construction[20] is about 82 percent of the total project costs mentioned earlier. China HSR with a maximum speed of 350 km/h has a typical infrastructure unit cost of about US$ 17-21m (RMB 100-125m) per km, with a high ratio of viaducts and tunnels. The cost of HSR construction in Europe, having design speed of 300 km/h or above is estimated to be of the order of US$25-39 m per km (see table 4 & 5). HSR construction cost (excluding land, rolling stock and interest during construction) is estimated to be as high as US$ 52m per km in California[21].

Based on D.P. Crozet[22], the unit cost for four HSR lines under construction in France in 2013 ranges between US$ 24.8m and 35.2m (Table 4).

**Table: 4 Estimated cost of the four lines under construction in France**

| | EAST Stras-bourg | BPL Brittany | CNM Nimes-Montpell-ier | Sud Europe Atlan-tique | Total |
|---|---|---|---|---|---|
| Total cost (Euro m) | 2 000 | 3 300 | 1 800 | 7 800 | 14 900 |
| Length (km) | 106 | 182 | 80 | 303 | 671 |
| Cost/km (Euro m) (US$ m) | 18.9 $25.9 | 18.1 $24.8 | 22.5 $30.8 | 25.7 $35.2 | 22.2 $30.4 |

**Table 5: Estimated Cost of Recent HSR Projects in Europe**

| High-Speed Rail Project | Length (km) | Approximate Construction Cost per km ($US 2012 m) | Construction Completion Date |
|---|---|---|---|
| Cordoba - Malaga (Spain) | 155 | $27 | 2007 |
| Madrid – Barcelona –Figueras (Spain) | 749 | $29 | 2008 |
| LGV East (France) | 300 | $31 | 2007 |
| Madrid – Valladolid (Spain) | 177 | $39 | 2007 |

Source: Texas A&M Transportation Institute (2013) based on US Government Accountability Office (2009)

It is apparent that the cost of construction of HSR in China is significantly lower than those listed in Tables 4 and 5, although comparison is at best approximate considering difference in accounting and cost procedures. Aside from the lower cost of

[18] http://en.wikipedia.org/wiki/Wuhan_Railway_Station
[19] From Baike.baidu.com
[20] Including civil works, track works, regular stations, yards, signaling, control and communication, power supply and other superstructure components; excluding the cost of planning, land, some of the mega stations, rolling stock and interest during construction.

[21] California HSR Authority, Draft Business Plan 2014
[22] International Transport Forum, December 2013

manpower, several other factors are likely to have led to lower HSR unit cost in China. At a program level, the declaration of a credible medium term plan for construction of 10,000 km of HSR in China over a period of 6-7 years energized the construction and equipment supply community to build capacity rapidly and adopt innovative techniques to take advantage of very high volumes of work related to HSR construction. This has led to lower unit costs as a result of the development of competitive multiple local sources for construction (earthworks, bridges, tunnels, EMU trains etc.) that adopted mechanization in construction and manufacturing. Further, large volumes and the ability to amortize capital investment in high-cost construction equipment over a number of projects contributed to the lowering of unit costs.

Other factors include a relatively low cost of land acquisition and resettlement[23], localization of the design and manufacture of goods and components as well as the standardization of designs for embankments, track, viaducts, electrification, signaling and communication systems. For example, the slab track manufacture process was imported from Germany but the cost of the Chinese made product is about a third lower than the German product as a result of large volumes and a lower labor cost. The technology developed for construction of tunnels not only resulted in a low unit cost but also a speed of 5-10 m of tunnel construction per day. The HSR tunnel construction cost in China (about US$ 10-15 million per km) is a fraction of that in other countries. [24] Tunnel costs are heavily influenced by geology and labor costs and, in the case of China, the latter has also helped in cost reduction.

[23] The cost for site work and right of way in California HSR is estimated at US$ 10 million per km contributing 17.6 percent of cost. In China Land acquisition and resettlement costs are still below 8 percent of project cost.

[24] Average tunnel costs per km are reported to be about US$ 43 m in New Zealand, US$ 50 m in the US and US$ 60 m in Australia (Analyzing Tunnel Cost, Efron and Read, 2012).

**Conclusions**

China Railway has accomplished a remarkable feat in building over 10,000 km of HSR network in a period of six to seven years at a unit cost that is lower than the cost of similar projects in other countries. The HSR network operates with high traffic volumes on its core corridors, and with good reliability. This has been accomplished at a cost which is at most two-thirds of that in the rest of the world. Besides the lower cost of labor in China, one possible reason for this is the large scale of the HSR network planned in China. This has allowed the standardization of the design of various construction elements, the development of innovative and competitive capacity for manufacture of equipment and construction and the amortization of the capital cost of construction equipment over a number of projects.

***Gerald Ollivier*** *is a Sr. Transport Specialist from the Beijing Office of the World Bank, leading or co leading teams working on Bank supported railway projects in China.*

***Jitendra Sondhi*** *is a railway engineer and is currently a Consultant to the World Bank's railway lending program in China.*

***Nanyan Zhou*** *is a transport consultant working with the World Bank and specializing in railway and traffic engineering.*

*This note is part of the China Transport Note Series to share experience about the transformation of the Chinese transport sector. For comments, please contact Gerald Ollivier (gollivier@worldbank.org).*