Dedicated High Speed Rail Network in India: Issues in Development

G Raghuram
Prashanth D Udayakumar

W.P. No. 2016-03-58
March 2016

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD-380 015
INDIA

Dedicated High Speed Rail Network in India: Issues in Development

G Raghuram
Professor, Public Systems Group
Indian Institute of Management Ahmedabad
Email: graghu@iima.ac.in

Prashanth D Udayakumar
Research Associate
Indian Institute of Management Ahmedabad
Email: updk2009@gmail.com

Abstract:

India and Japan have signed a memorandum of understanding to set up a high speed rail (HSR) network costing INR 976.36 billion, between Mumbai and Ahmedabad. As of now, the top speed in India is 150 kmph, and that too for a few special trains in limited segments of their run. The Ministry of Railways first proposed HSR in 2007-08 and have conducted pre-feasibility studies on various routes in the country.

While documenting the progress of proposed HSR routes for India, the paper also draws lessons from international HSR experience in Europe and Asia. For the development of HSR network in India, there are a variety of issues. This paper examines issues with regards to route fixation, choice of technology partner and need for standards, location of stations, choice of grade level, choice of gauge and interoperability of trains beyond core networks, and pricing, revenues and funding.

Keywords: high speed rail; Indian Railways; Shatabdi Express; Shinkansen

Dedicated High Speed Rail Network in India: Issues in Development

1 Introduction

In December 2015, India and Japan signed a memorandum of understanding (MoU) to set up a high speed rail (HSR) network costing INR 976.36 billion, between Mumbai and Ahmedabad.[1] Japan would fund $12 billion (about INR 781 billion, providing for about 80% of the project cost) offering a concessional loan to India with a repayment period of 50 years including a moratorium of 15 years, at an interest rate of 0.1%. This segment for HSR implementation would be based on the Japanese Shinkansen technology.

As of March 2016, most of the express trains in India were running at top speeds of 110 kmph. The Bhopal Shatabdi Express was India's fastest train with a top speed of 150 kmph. Longer distance trains like the Rajdhani Express and Garib Rath Express had top speeds of 130 kmph. Gatimaan Express, the semi-HSR service planned between the 200 km Delhi Agra stretch, was expected to run at top speeds of 160 kmph. Though originally scheduled to be launched in 2015, safety requirements of the Commission of Railway Safety (CRS) caused delays.[2] Though originally planned to cover the stretch in 90 minutes, the trial run on March 22, 2016 took 113 minutes, just four minutes faster than the time taken by the Shatabdi Express.[3] This was due to a variety of inhibiting factors including 19 'caution points' (curves, bridges and populated sections) and the Mathura railway yard which needs signalling upgradation.[4] With a few more trials, the travel time was expected to reach 110 minutes.[5] Such a situation of limited marginal value is not specific to just the Delhi-Agra route. The trains which are capable of running at speeds higher than 110 kmph are firstly few in number, and are in a position to achieve the higher speeds only in limited segments of their run.

The Indian Railways (IR) has been considering two options for speeding up the rail route network – building of dedicated HSR lines and upgrading the existing tracks to semi-HSR lines. Both the options have their own advantages and disadvantages. HSR caters to speeds of up to 350 kmph while semi-HSR up to 200 kmph. Dedicated lines built for HSR cost about INR 2 billion/km while upgrading existing tracks for semi-HSR costs about INR 0.1 billion/km. Dedicated HSR would offer ease of operations while the semi-HSR would increase operational complexity and may even bring down overall throughput, since the right of way would be shared with the conventional trains.

This paper accepts the premise that the dedicated HSR is the way to go. It builds on the roundtable held in New Delhi in December 2013 where Raghuram[6] presented on the issues in developing HSR in India. The history of HSR planning in India till 2015 is summarized in the next section. The paper discusses HSR in other countries (Europe and Asia) in section 3, attempting to draw lessons from such experience. Section 4 brings out the existing and potential issues in the development of HSR in India. Section 5 concludes with recommendations and major points that the developing authority needs to keep in mind. Overall, the paper attempts to provide a status report on the potential of HSR in India.

2 HSR Planning in India

[1] (Das, Japan hands out sweat deal for bullet train; beats expectations on soft loan terms, 2016)
[2] (Delhi to Agra in 90 minutes flat, 2016)
[3] (Dastidar, 2016)
[4] (Dastidar, 2016)
[5] (Dastidar, 2016)
[6] (Raghuram, HSR in India, 2013)

2.1 HSR Proposals

IR first proposed five HSR routes during the 2007-08 Railway Budget. In the 2009-10 Railway Budget, one more route was proposed. In December 2009, the Vision 2020 of the Ministry of Railways (Ministry) envisaged the implementation of at least four HSR projects, one each in the Northern, Western, Southern and Eastern regions of India. The six routes proposed in the 2007-08 and 2009-10 Budgets were also recommended in the Report of the Expert Group for Modernisation of Indian Railways in February 2012. In the 2012-13 and 2014-15 Railway Budgets, one route each was added, taking the number of routes proposed by the Ministry to eight. Due to the higher construction costs involved in the ghat section of the Mumbai-Ahmedabad-Pune route, the Mumbai-Pune link was dropped in a Railway Board decision in March 2013.[7]

In the 2009-10 Kerala State Budget, the Thiruvananthapuram-Kasargod-Mangalore route was proposed, given the high population density of Kerala along its linear geography. In 2011, at the Kerala government's request, Thiruvananthapuram was added to the Chennai-Bangalore-Ernakulam route.[8]

Table 1 chronologically lists the HSR corridors proposed and modified since 2007-08. As of early 2016, nine routes were being considered by the IR and the Kerala government, the progress of which is reported in Appendix A.

Budget	Route	Route length (km)
Railway Budget 2007-08	Delhi-Amritsar	450
	Ahmedabad-Mumbai-Pune	650
	Hyderabad-Vijayawada-Chennai	664
	Chennai-Bangalore-Ernakulam	649
	Howrah-Haldia	135
Railway Budget 2009-10	Delhi–Patna	991
Kerala State Budget 2009-10	Thiruvananthapuram-Kasargod-Mangalore	585
Kerala Government's request to Central Government	Chennai-Bangalore-Ernakulam-Thiruvananthapuram	850
Railway Budget 2012-13	Delhi-Jaipur-Ajmer-Jodhpur	591
Railway Budget 2013-14	Mumbai-Ahmedabad	534
Railway Budget 2014-15	The Diamond Quadrilateral – to connect Delhi, Mumbai, Kolkata and Chennai, and to connect the two diagonals	10,000

Table 1: Evolution of Identified HSR Routes

2.2 High Speed Rail Corporations

[7] (Rashid, 2013)
[8] (Chennai-Ernakulam High Speed Rail Corridor to be extended, 2011)

The Central Government formed the High Speed Rail Corporation of India Limited (HSRC), as an SPV and a subsidiary of Rail Vikas Nigam Limited (RVNL), for the development and implementation of HSR projects.[9] RVNL is a wholly owned subsidiary of the IR. HSRC was incorporated on July 25, 2012 and launched on October 29, 2013.[10] Its stated objectives[11] are:

- "To undertake feasibility studies and techno-economic investigations and prepares detailed project reports and bankability reports of selected corridors.
- To plan, design and freeze technical parameters including fixed assets, rolling stock and operations.
- To develop financing models, explore PPP options, coordinate with stake holders and funding agencies and obtain various Government approvals.
- Project development, project execution, construction, upgradation, manufacture, operation and maintenance of HSR systems on existing as well as new rail corridors.
- To enter into and carry on all businesses related to HSR Systems and other rail based traffic as may be approved by Government of India or RVNL or any other Authority created by the Government for such activities."

An MoU was signed between Japan International Cooperation Agency (JICA) and the Ministry on October 7, 2013 for conducting a joint feasibility study for Mumbai - Ahmedabad HSR system.[12] The Railway Board associated HSRC with the study, the report for which was submitted in July 2015 and was accepted by the Ministry.

The 12th Five-Year Plan (2012-17) proposed to set up a National High Speed Rail Authority (NHSRA), through a Bill in Parliament, as an autonomous body for implementation of IR's HSR projects. NHSRA would be entrusted with the work of planning, standard setting, implementing and monitoring these projects.[13] While NHSRA would be responsible for policy formation, HSRC would be responsible for implementation.[14] In March 2012, the Ministry said that the draft bill for the formation of NHSRA has been moved for approval of the Government.[15]

After signing the MoU with Japan for financing the Mumbai-Ahmedabad HSR, the Central Government set up a panel under the NITI Aayog to sort out bilateral issues with their Japanese counterparts in January 2016.[16] On February 12, 2016, a company called National High Speed Rail Corporation was incorporated under the Ministry to implement the Mumbai-Ahmedabad HSR with Japanese financial and

[9] (HSRC, 2013)
[10] (HSRC, 2013)
[11] (HSRC, 2013)
[12] (Raghuram, HSR in India, 2013)
[13] (Planning Commission)
[14] (Soni, 2013)
[15] (Present Status of High Speed Rail Corridors, 2012)
[16] (PTI, 2016)

technical assistance.[17] This corporation will be jointly held by the Ministry (50%) and the states of Maharashtra (25%) and Gujarat (25%).

3 HSR from an International Perspective

3.1 Definition

The European Union Directive 96/48/EC, defines HSR with precise criteria that can be abstracted as below.[18]

a) Infrastructure: Tracks built specially for high-speed travel or specially upgraded for high-speed travel (including intermediate connecting lines).

b) Rolling Stock: Trains at speeds more than 250 kmph on specially built HSR lines or trains at speeds more than 200 kmph on upgraded lines.

c) Compatibility of infrastructure and rolling stock to ensure performance levels, safety, quality of service and cost.

3.2 HSR in Various Countries

As of April 2015, the total length of HSR networks in the world is 29,792 km. Table 2 lists the countries with an operational HSR network length of more than 100 km, with their route lengths, electrification specification and gauge type.

S. No.	Country	In operation (km)	Under Construction (km)	Total Country (km)	Electrification	Track Gauge (mm)
1.	China	19000	12000	31000	25 kV 50 Hz	1435
2.	Spain	3100	1800	4900	25 kV 50 Hz	1435
3.	Japan	2664	782	3446	25 kV 50/60 Hz	1435
4.	France	2036	757	2793	25 kV 50 Hz (partially)	1435
5.	Turkey	1420	1506	2926	25 kV 50 Hz	1435
6.	Germany	1334	428	1762	15 kV 16.7 Hz	1435
7.	Italy	923	395	1318	25 kV 50 Hz, 3 kV DC	1435
8.	Russia	649	770	1419		1520
9.	South Korea	412	562	974	25 kV 60 Hz	1435
10.	Taiwan	345	0	345	25 kV 60 Hz	1435
11.	Uzbekistan	344	0	344		1520
12.	Belgium	209	0	209	25 kV 50 Hz	1435
13.	Netherlands	120	0	120	25 kV 50 Hz	1435
14.	United Kingdom	113	204	307	25 kV 50 Hz	1435

Table 2: HSR Overview by Country[19]

---

[17] (Press Information Bureau, 2016)
[18] (High Speed, 2016)
[19] Sourced from: CNTV (2016); Railway Technology (2015); TheCityFix (2013); Japan Railway & Transport Review (1998), UIC (2015), World Bank (2014), © OECD/ITF (2014); European Railway

In this section, HSR experiences and major lessons learnt from four Asian and five European HSR schemes are discussed.

3.2.1 **Japan**

Opened in 1964 between Tokyo and Shin Osaka, the Tokaido Shinkansen in Japan is the first HSR network in the world developed by the Japanese National Railways. The first route between Japan's two largest cities, and passing through a highly populated and economically developed corridor of 515 km, was well received. While there was an attempt to use the existing main railway stations for the HSR, many cities were served by new (Shin) stations like Shin Osaka, due to problems (and costs) of accessing the main station. However, it was most often ensured that the new station had conventional rail connectivity to the main station.

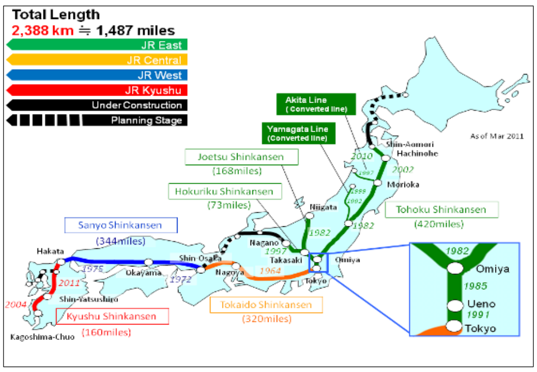

Figure 1: HSR Map of Japan[20]

The Shinkansen network was privatised when the JR Group (consisting of four companies) took over from the Japan National Railways in 1987. The dedicated network uses the standard gauge, though the earlier rail networks in Japan used a narrow gauge of 1067 mm. Known for its safety record of zero fatalities since 1964[21], Shinkansen has epitomised the high safety levels of HSR compared to other transport modes. With respect to air pollution, the amount of CO_2 per unit transport volume produced directly by the Shinkansen is only 16% that of a passenger car.[22] The Japanese HSR also maintains a high degree of punctuality, which becomes all the more important given the tight schedules of the high traffic network. A map of Japan's HSR network is shown in Figure 1. As of 2011, the total traffic in the Japanese HSR had crossed 318 million per annum.

Suicides by jumping onto railway tracks in front of trains, heavy snow during winter, and earthquakes have been safety issues. Noise pollution, especially the tunnel boom phenomenon, also has been a concern.

3.2.2 **Italy**

The first dedicated HSR line in Europe partially started operations in 1978 when the Rome-Florence 'Direttissima' line of 252 km opened.[23] Italy uses both tilting and non-tilting trains in its HSR services, that are operated by the state-owned subsidiary

Review (2015); One Europe (2015); UzDaily (2011); Oriental Express Central Asia; M. Finger and P. Messulam (2015); Russian Railways (2009); Russian Railways (2015); Taiwan HSR; J. Ni & J. Chang (2012); S. Kim et al. (2009); F. Hanna & J.Kaufmann (2014); R. Casale (n.d.)

[20] (Ministry of Land, Infrastructure, Transport and Tourism, Japan, n.d.)

[21] (About the Shinkansen: Safety, n.d.)

[22] (Okada)

[23] (High Speed Rail Operations, Italy, n.d.)

Trentialia and the privately owned (Europe's first) NUV, with top speeds of 300 kmph. A map of Italy's HSR network is shown in Figure 2.

Figure 2: HSR Map of Italy[24]

There were delays in launch of services by NUV in 2011, after RFI (the infrastructure manager and subsidiary of the government) changed its "network statement," days after NUV had lodged an "application for paths."[25] NUV finally started operations in April 2012. The "heads-on" competition between the two operators has led to a decrease in fares and increases in service and ridership.[26]

3.2.3 France

Figure 3: TGV's HSR Network in France

The first line of the French HSR network was the LGV Sud-Est (French for South-East high-speed line) which opened in 1981 between Paris and Lyon, a distance of about 460 km. Operated by SNCF Voyages, a subsidiary of the state-owned railway company, the network grew with more lines like the LGV Nord, LGV Est, LGV Atlantique, LGV Rhône-Alpes, and LGV Méditerranée. The trains are called TGV (French abbreviation for high speed train) and were developed during the 1970s by Alstom and SNCF. HSR traffic accounts for 60% of overall rail traffic in France.[27] The stations for medium-sized cities are built outside the town to avoid increases in journey times.[28] Service frequencies to a particular city depend on the population.[29] Figure 3 shows a map of TGV's HSR network.

TGV tracks are known for their large radii of curvature (more than 4 km on older lines and more than 7 km on new lines) which are an important planning aspect to allow for greater speeds in the future. This also manages the centripetal acceleration felt by passengers. Tunnels have greater-than-normal diameters to limit the effects of air pressure changes and tunnel boom. France has had a near-zero fatality record in high speed trains running on LGV lines, thanks to the articulated design of the trains.

[24] (EuRail, n.d.)
[25] (NTV brands RFI access changes 'illegal', 2011)
[26] (Crozet, 2013)
[27] (Crozet, 2013)
[28] (Crozet, 2013)
[29] (Crozet, 2013)

In case of a derailment, the semi-permanently coupled articulated un-powered coaches of TGV are more likely to stay upright and in line with the track.

3.2.4 Germany

The first regularly scheduled HSR trains in Germany ran on June 2, 1991. The InterCityExpress (ICE) trains are high speed train services offered by the DB Fernverkehr division of Deutsche Bahn, the German railway company – private joint-stock but with 100% stockholding by the Federal Republic of Germany. There are many classes of ICE trainsets, with ICE 4 (earlier called ICx) being the latest. ICE 3 trains run at a maximum speed of 320 kmph. Like many European countries, the ICE is also connected to neighbouring countries - Denmark, the Netherlands, Belgium, France, Switzerland and Austria.[30] Figure 4 shows ICE's HSR network in Germany.

Figure 3: ICE's HSR Network in Germany[31]

Germany, with its unique urban geography, has trains stopping at conventional rail stations at city centres.[32] The HSR network is integrated well with the rest of the rail network, with the HSR trains making "frequent incursions" into the conventional rail network to reach stations.[33] With medium-sized cities not far away from each other, Germany's HSR service is used for short to medium distances and runs at speeds of 200 to 250 kmph.[34]

On June 3, 1998, the ICE884 Munich-Hamburg train derailed near Eschede and crashed onto a bridge, bringing it down. About 102 people died in the crash during which the train was reportedly travelling at about 200 kmph. The accident was believed to have been caused by a cracking inside the ring of the wheel, caused by excessive wear and tear.[35]

3.2.5 Spain

Spain's first HSR line opened in 1992, connecting Madrid, Cordoba and Seville. Alta Velocidad Española (AVE), the HSR service, is operated by Renfe Operadora, the state-owned railway company. The railway infrastructure, including track, signalling and stations, are managed by ADIF, another state-owned company. Spain's HSR has a network length of 3100 km (as of June 2013), the longest in Europe, and operates at a maximum speed of 310 kmph. Figure 5 shows a map of Spain's HSR network.

[30] (ICE high-speed train, 2015)
[31] (EuRail, n.d.)
[32] (Crozet, 2013)
[33] (Crozet, 2013)
[34] (Crozet, 2013)
[35] (ICE Train Accident in Eschede - Recent News Summary, 2000)

Figure 4: HSR Network in Spain[36]

Though Spain has traditionally used the Iberian gauge (1668 mm) operated by RENFE and metre gauge (1000 mm) operated by erstwhile FEVE, it decided to use standard gauge for HSR. With a focus on interoperability, three generations of gauge interchange systems have appeared in Spain, with the latest seen in the CAF-Alstom ATPRD s-120 engines that can change gauges at a speed of 30 kmph using the Brava system developed by CAF.[37]

After introducing a market-based fare structure with discounts in February 2013, RENFE recorded a 23.47% increase in annual ridership from 12 million to reach 14.9 million over the period ending in February 2014.[38] Over the same period, there was a 6.95% increase in revenue and occupancy increased to 73% up from 65%.[39]

In July 2013, an Alvia HSR train derailed near the Santiago de Compostela railway station killing more than 79 people. The driver was charged for driving at 190 kmph on a curve with a speed limit of 80 kmph.[40]

3.2.6 **United Kingdom**

Figure 6: HSR Map of UK

Opened in 2003, the Channel Tunnel Rail Link (CTRL), now known as High Speed 1 (HS1), is the first high speed line to be built in the United Kingdom (UK) and was constructed and operated by London & Continental Railways (LCR). Section 1 (Channel Tunnel to Fawkham Junction, Kent) opened in 2003 and Section 2 (Ebbsfleet, Kent to London St. Pancras) opened in 2007. The Channel Tunnel is the international railway link between UK (HS1) and France (LGV Nord) operated by Eurostar. The HS1 line has Eurostar international services operating at speeds up to 300 kmph and Southeastern domestic passenger services at speeds up to 225 kmph. In the Channel Tunnel, trains run at a maximum speed of 160 kmph.

---

[36] (EuRail, n.d.)
[37] (EFRTC, 2007)
[38] (New fares boost high speed traffic, 2014)
[39] (New fares boost high speed traffic, 2014)
[40] (Penhaul, Maestro, & Smith-Spark, 2013)

Many mobile network operators provide calls, text and data services to customers travelling through the Channel Tunnel.[41] Figure 6 shows the HS1 and the upcoming HS2 network in the UK.

In June 2009, the UK government bought over LCR, with the latter having a government-guaranteed financial debt of GBP 5.169 billion.[42] Later in November 2010, the government awarded a 30-year concession to a consortium of Borealis Infrastructure and Ontario Teachers' Pension Plan for GBP 2.1 billion to manage the 109 km HS1 line, while ownership of the infrastructure and land remained with the government.[43]

3.2.7 China

Starting 1997, the ‘China Railway Speed Up Campaign’ involved speeding up of rail services in China. By the sixth and final round of the campaign, about 6000 km of tracks could run trains at speeds up to 200 kmph.[44] China introduced its first HSR line in 2004 that uses magnetic levitation (maglev) technology – the 30 km Shanghai Transrapid from the Shanghai International Airport to the Longyang Road station of the Shanghai Metro. Amidst debates on whether it should adopt the maglev tracks for the rest of the HSR, China continued with the wheeled rails and standard gauge of the conventional rail network for its HSR. Going on from the first line that opened in April 2007, China’s HSR has grown to 19,000 km of HSR in 2015, which is two-thirds of the world HSR network. China’s HSR network now primarily consists of the newly built passenger-designated lines, newly built conventional lines that carry high speed passenger trains and freight trains, newly built regional intercity lines for high speed trains, and upgraded conventional lines. The Harbin-Wuhan train (covering 2421 km in 14.5 hours), which began service in December 2014, became the then longest HSR service in the world.[45] Figure 7 shows the HSR map of China.

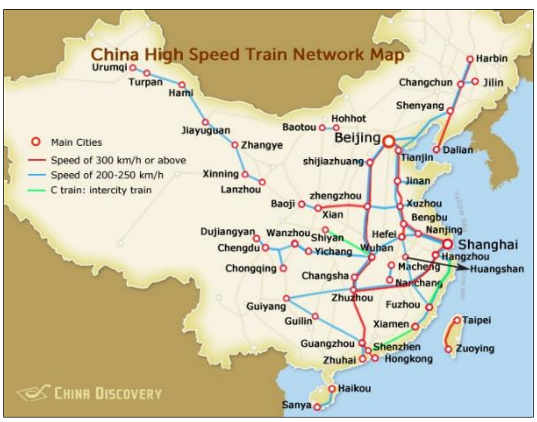

Figure 5: HSR Network in China[46]

Most of the rolling stock and operations are public-owned. China's high speed trains have been imported; built under technology transfer agreements with foreign train-makers including Siemens, Bombardier and Kawasaki Heavy Industries.[47] They have been re-designed

[41] (Garwood, 2014)
[42] (Government takes control of London & Continental Railways, 2009)
[43] (High Speed 1 concession awarded to Canadian pension consortium, 2010)
[44] (High Beam, n.d.)
[45] (eChinacities.com, 2014)
[46] (China Discovery, n.d.)
[47] (Kanwal, 2015)

indigenously to reach operational speeds of up to 380 kmph.[48] However, train operating speeds were limited to 300 kmph to save energy and operating costs in 2011.

In July 2011, lightning and subsequent signalling equipment failure resulted in a crash involving two HSR trains near Wenzhou, in which 40 people died and 191 were injured.[49]

3.2.8 South Korea

The Korea Train eXpress (KTX) is the HSR service that is run and owned by KoRail, the state-owned railways operator of South Korea. Construction began in 1992 and the Gyeongbu HSR, the first KTX line, was launched in April 2004 between Seoul and Busan, with a length of 423 km. With only Phase I from Seoul to Dongdaegu having newly-constructed tracks, Phase II from Dongdaegu to Busan ran on electrified existing lines. The impact was immediate. The average daily ridership in the air segment of the Seoul-Deagu and Seoul-Busan routes decreased by 78.7% and 36.6% between 2003-04 and 2004-05.[50]

Phase II's newly constructed HSR tracks opened in 2010. The second HSR line - Honam HSR - of 182.3 km from Osong to Mokpo was opened in April 2015.[51] Trains run at a maximum speed of 305 kmph. Figure 8 shows the HSR map of South Korea.

The Ministry of Construction and Transportation included fire preventing standards in its plans for high speed railroad tunnels only in November 2003, after most of the tunnels for the Gyeongbu HSR were almost complete.[52] Japan's Department of National Transportation regulates that "bullet train tunnel emergency routes should not exceed 500m in case of fires and other emergencies."[53] In a separate issue in 2009, cracks developed on sleepers of tracks in phase 2 of the Gyeongbu line due to blueprints not being followed by the manufacturers.[54]

Figure 6: HSR Network of South Korea[55]

After the first experimental HSR train Hanvit-350, Korea developed and launched KTX-Sancheon in March 2010[56], which ran into issues after 53 reported operational

48 (Kanwal, 2015)
49 (LaFraniere, 2011)
50 (Effects of Korean Train Express (KTX) Operation on the National Transport System, 2005)
51 (Honam high speed railway inaugurated, 2015)
52 (What If There Is a Fire in a Railroad Tunnel?, 2005)
53 (What If There Is a Fire in a Railroad Tunnel?, 2005)
54 (KTX Is a Disaster Waiting to Happen, 2009)
55 (Korean Culture and Information Service, Ministry of Culture, Sports and Tourism; KOREA.net, n.d.)
56 (Korea Railroad Corporation, n.d.)

glitches in 2010. There was also a derailment at a switch in February 2011 at 90 kmph attributed to a combination of improper maintenance by a subcontractor and mishandling of faulty signal equipment by Korail officials. [57] In May 2011, Korail asked Hyundai to recall the 19 sets of HTX-Sancheon and investigate the causes.[58]

In certain segments of tracks for joint use between conventional rail and HSR, there were increases in journey time noticed in conventional rail services due to capacity limitation and stoppages at more stations to compensate for increased headway.[59] This also contributed to modal shift from conventional rail to HSR.

3.2.9 Chinese Taipei (Taiwan)

Most of Taiwan's population lives along the western length of the island. Privately constructed, the Taiwanese HSR is run by the Taiwan High Speed Rail Corporation (THSRC). The HSR service of 435 km between Taipei and Kaohsiung is run at speeds of up to 300 kmph. The service with least number of stops (at Banqiao and Taichung) takes 96 to 102 minutes. The double-tracked line, except for 3km of traditional ballasted tracks, uses Japanese-designed slab tracks.[60] There are also dedicated animal crossings.[61] Figure 9 shows the map of the Taiwan HSR.

The high cost of the Taiwan HSR system – about $ 15 billion – invited criticisms before the opening of the line on January 4, 2007. Table 3 lists the break-up of expenses between the government and the private sector.

Figure 7: HSR Map of Taiwan[62]

Under the terms of the 35-year built-operate-transfer concession, THSRC had to pay the government 10% of its pre-tax profits each year, and a minimum of TWD 108 billion in total.[63]

THSRC had an additional 50-year concession for commercial development of land around its stations.[64] In 2009, a re-election to the board saw government-appointed members filling the majority of seats.[65] In the same year, there was also a refinancing of the project with a syndicate of government-dominated banks at lower interest rates.[66] After continued "long-term losses", both the concessions were terminated in

57 (Hyo-sik, KTX causes safety concern, 2011)
58 (Hyo-sik, KTX-Sancheon recalled after series of breakdowns, 2011)
59 (Effects of Korean Train Express (KTX) Operation on the National Transport System, 2005)
60 (Taiwan, Taiwan, n.d.)
61 (Taiwan, Taiwan, n.d.)
62 (Ministry of Foreign Affairs, Republic of China (Taiwan), n.d.)
63 (Taiwan's high speed line takes off, 2007)
64 (Taiwan's high speed line takes off, 2007)
65 (Huang, 2009)
66 (Taiwan high speed rail refinancing agreed, 2009)

July 2015.[67] THSRC, however, was to continue to operate the services, with the government institutions' share in the holdings to increase from 22.1% to 63.9% and large private shareholdings to come down from 37.4% to 17.4%.[68]

Party	Expenses	Amount (TWD billion)
Government	Land acquisition, planning and construction of underground section through Taipei	105.7
Private sector	Construction	325.9
Private sector	Financing costs	81.7
	Total	513.3

Table 3: Breakup of Expenses for the Taiwan HSR[69]

In July 2011, the government had to come up with a plan to close about 1,000 deep wells to check ground subsidence. In the worst affected section of the HSR line, the average subsidence was 6.4 cm.[70]

3.3 Investment in HSR

Along with the basic objectives of increasing capacity and speed, other factors like improved journey time reliability, economic development, political integration and environmental concerns also affect service design of the HSR projects.[71] Against Preston's list of objectives of various HSR schemes worldwide[72], we have marked some of India's own possible objectives in Table 4.

Objective	France	Japan	China	Italy	UK	Taiwan	Spain	India
Speed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Capacity	Yes	Yes	Yes	Yes	Yes (HS2)	Yes		Yes
Reliability				Yes	Yes (HS1)			
Economic Development			Yes		Yes	Yes		Yes
Environment					Yes (HS2)			
Supply Industry	Yes	Yes	Yes				Yes	Yes
Prestige	Yes		Yes	Yes			Yes	Yes
Political Integration			Yes				Yes	Yes

Table 4: Objectives of HSR Schemes

[67] (Government becomes majority shareholder in Taiwan High Speed Rail Corp, 2015)
[68] (Government becomes majority shareholder in Taiwan High Speed Rail Corp, 2015)
[69] (Taiwan's high speed line takes off, 2007)
[70] (Hsiu-chuan, 2011)
[71] (Preston, 2013, p. 12)
[72] (Preston, 2013, p. 12)

While discussing approaches to assess HSR schemes, Preston points to the 'paralysis by analysis' in the UK and the US, and the 'build it and see' approach in China and Spain. He suggests a 'step by step' approach as opposed to a 'big bang approach' where HSR investments are considered at an incremental level - the best lines are identified and then the network evolution is planned.

His four-stage test for HSR investments:[73]

1) Does the HSR make a commercial (financial) return?
   Few HSR schemes like the Tokaido (Tokyo-Osaka) and Sanyo Shinkansen (which combined had 207 million passengers in 2011), and the TGV Sud-Est (Paris-Lyon) have made financial returns. In China, of four recent openings studied, only the Jinan-Qingdao line is covering financial costs. These have first year usage in excess of 20 million passengers per annum. Where fares are based on full cost recovery and where income levels are not commensurate, HSR could exhibit commercial difficulties.
2) Does the HSR make a social return, based on rail transport benefits only?
   Social returns would include non-fare box revenues and benefits due to lesser impact on the environment. A social breakeven approach with a benefit-cost ratio (BCR) of 1 might have many HSR systems pass this stage, with de Rues and Nash[74] postulating 9 million passengers per annum. However, considering opportunity costs of constrained budgets, a higher BCR might have to be used. For example, UK used 2 till recently while Germany uses 3.
3) Does the HSR make a social return, including quantified impacts on other transport systems (air and road) and wider economic benefits?
   The case for HS2 in the UK is an example. Connectivity to labour markets and connectivity between businesses and consumers promotes agglomeration economies, which impact on other modes of transport. Modelling of the entire transport system for estimation, however, has uncertainties in terms of the magnitude and additivity of wider economic benefits.
4) Does the HSR make a social return, when qualitative wider benefits are taken into account?
   Qualitative benefits would include technology development, industrial growth, etc.

A failure in the four-stage test would need a strong rationale behind spending public money on HSR as opposed to other transport modes.

3.3.1 Costs and Benefits

Dedicated infrastructure for high-speed passenger lines frees up capacity on conventional lines, which can be used to accommodate additional freight and conventional passenger trains.[75] In turn, this helps relieve congestion on the roads

[73] (Preston, 2013, p. 32)
[74] (de Rues and Nash, 2007, p.32) quoted in (Preston, 2013)
[75] (Raghuram, High Speed Rail in India, 2014)

and drive down the related costs to society. Other than those listed in Table 4, benefits of HSR include safety, revenue, reductions in conventional rail overcrowding, energy security (electrified HSR), decongestion of tier-I cities and other wider economic benefits.[76] HSR would create better tourist connectivity and real estate development, promote balanced and inclusive regional development, and provide greater access to health and education.[77] Traffic control systems and infrastructure of HSR are simpler to control, compared to aircrafts.[78]

Environmental benefits in HSR over conventional rail are marginal, taking decades for it to compensate for the much higher emissions during construction and higher energy costs during operation.[79] With respect to CO_2 emissions, HSR will lead to net environmental betterment across transport modes if there is a large shift from other modes like air and road (car).[80] Total CO_2 emissions per 100 passenger km by HSR are four times less than by air travel and three times less than by car travel.[81] However, CO_2 emission reductions depend on speed and distance between stops, capacity utilisation and carbon content of electricity.[82] Emission reductions are significant only in the de-carbonised electrification scenario.[83] There are also issues regarding the use of tunnels, of large land take (impact on biodiversity) and noise pollution (if not properly addressed).

HSR's high utilisation of rolling stock and crew members offset the higher energy and maintenance costs compared to conventional rail.[84] Concrete slab tracks cost have greater construction costs and carbon intensity, but lower maintenance costs.[85] While economies of scale and technological advances might lead to lowering of costs over time, higher regulatory standards (environmental, safety, etc.) might increase the same.[86] Shift of modal share from heavily taxed road to rail can affect the government if there are grants or subsidies towards HSR[87] (though this is unlikely in India given the premium nature of HSR travel). HSR is more efficient on land use, with an average HSR line using 3.2 ha per route km compared to 9.3 ha per route km for an average six-laned highway.[88] Whether the project is commercially driven or is run as a public utility could make a difference in public opposition to land acquisition and environmental costs.

While there have been cases of fatal accidents in China and Europe, Japan's Shinkansen has had an impeccable safety record with zero fatalities.

[76] (Prasad)
[77] (Shukla, Pathak, Mittal, & Dhar, 2015)
[78] (Draft Report of Working Group on Railways Sector, set up by NTDPC)
[79] (Preston, 2013)
[80] (Preston, 2013)
[81] (Shukla, Pathak, Mittal, & Dhar, 2015)
[82] (Shukla, Pathak, Mittal, & Dhar, 2015)
[83] (Shukla, Pathak, Mittal, & Dhar, 2015)
[84] (Preston, 2013)
[85] (Preston, 2013)
[86] (Preston, 2013)
[87] (Preston, 2013)
[88] (Shukla, Pathak, Mittal, & Dhar, 2015)

Construction costs per route km in HSR vary, with the lowest being achieved in France (EUR 4.7 – 18.1 million, 2005 prices), Spain (EUR 7.8-20 million, 2005 prices) and China (at 2010 prices, 12 lines with design speeds of 250 kmph average at around EUR 8.8 million, whereas ten lines with design speeds of 350 kmph average at EUR 16.5 million). For China, Preston references Wu[89] noting that the split between infrastructure, superstructure and land/other costs are typically 60:20:20, with station costs adding an additional 10% to 30%. On the higher side, the HS1 in the UK costed EUR 31 million per km for Phase I and EUR 117 million for Phase II (with about 21.5 km of tunnel length out of a total 39 route km). Chinese Taipei (76% elevated and 11% tunnel) had a construction cost of EUR 39.5 million per route km at 2005 prices. Therefore, design operating speeds/gradients, topography, population density (land costs; grade levels), and access to central area by existing rights of way, are important drivers of construction costs.

However, ex-post evaluations of HSR lines in France, except for the Sud-Est, have shown financial and socio-economic internal rates of return much lower than the ex-ante evaluations. The Madrid-Seville and Madrid –Barcelona lines in Spain have not done well either.

3.3.2 Demand Levels and Ridership: Modal Shift

As seen from analysis of HSR investments in Spain, business travelers appear to be main beneficiaries of HSR.[90] The roundtable had noted that the “primary focus of HSR was to serve long distance business and leisure travel markets.”[91] Evidence from five existing European HSR schemes show that around 30% of the HSR demand is shifted from air, 30% from conventional rail, 15% from road and 25% from generated traffic.[92] While forecasting such intermodal shift for India, it should be noted that the air travel market is not as big as in Europe or the West, making conventional rail and road the major sources. At the roundtable, demand in India was not seen as a major problem.[93]

Using a framework developed by de Rues et al. to determine break-even values for HSR in China, Wu[94] found that a traffic density of between 40 and 50 million passengers per annum is required to achieve commercial break-even for HSR lines with 350 kmph operating speeds, and between 25 and 30 million for lines capable of 250 kmph operating speeds.[95] HSR demand in China has not been high, though it may improve when schemes are completed.[96] Preston reports that Wu shows a mean demand of 18.4 million on 15 lines.[97] Fares are relatively high as a proportion of

[89] (Wu, 2013)
[90] (Preston, 2013)
[91] (Preston, 2013)
[92] (Preston, 2013)
[93] (Preston, 2013)
[94] (Wu, 2013) quoted in (Preston, 2013)
[95] (Preston, 2013)
[96] (Preston, 2013)
[97] (Wu, 2013) quoted in (Preston, 2013)

income and when compared to conventional rail. Station location, in areas marked for new development, could also be a reason.[98]

At 300-350 kmph, HSR has advantages over air for medium distances up to 1000 km as access/egress and waiting times are higher for air travel. The higher affordability of initial HSR users would mean higher time value. So, out-of-city HSR stations have a negative effect on ridership. Good last-mile connectivity, either through intermodal infrastructure or through interoperability of HSR on conventional tracks for certain schedules, would go a long way in attracting the car and air segments.

A study of market shares between HSR and air in relation to the travel time excess of HSR over air on routes in Europe show that the key threshold journey difference is around two hours i.e. an absolute rail journey time of around three hours that permits a same day return.[99] Madrid-Barcelona (2010 data), an outlier in the pattern suggests that other factors, including competition from air in terms of frequency and fare, may be important. Preston[100] believes there could be a threshold of around ten hours for overnight travel; examples are New Delhi-Chennai (2176 km) and Beijing-Hong Kong (2475 km). For intermediate journey times, passengers might prefer conventional rail or air services.

Table 5 shows the comparison of various countries on the share of modal shift from other transport modes to HSR, with examples from France, Spain, Belgium, Eurostar, China and a forecast for the Indian route of Mumbai-Ahmedabad.

Route	Paris - Lyon	Madrid -Seville	Madrid-Barcelona	Thalys	Eurostar	Beijing-Tianjin[101]	Mumbai-Ahmedabad[102]
% HST traffic generated from:	1980 to 1985	1991 to 1996 forecast	'Before HSR' to 'After HSR'	Range not given	Range not given	2011	2035 estimated
Induced	29	50	20	11	20	44	-
Road	11	6	10	34	19	9	48
Conventional rail	40[103]	20	10	47	12	48	39
Air	20	24	60	8	49	-	13

Table 5: Diversion Factors Resulting from Introduction of HSR[104]

Besides competition, collaboration would also help. While getting a lot of modal shift from the medium-distance air passengers, HSR could act as the spokes for long-

[98] (Preston, 2013)
[99] (Preston, 2013)
[100] (Preston, 2013)
[101] (Wu, 2013) quoted in (Preston, 2013)
[102] (Pal, 2013) quoted in (Preston, 2013)
[103] All Paris-Lyon's 'after' rail travel is presumed to be by HST (i.e. no conventional rail following introduction of HST), since alternative journey time is ~5 hours compared to ~2 hours by HST. (Quoted from Preston 2013)
[104] Bonnafous, 1987; de Rus and Inglada 1997; Coto-Millán et al., 2007; Segal, 2006; Quoted in Preston, 2009 & 2013

distance routes at hub airports. Optimal time scheduling of HSR services at such interchanges and at regional bus/train stations would be needed.[105]

4 Issues with HSR in India

This section discusses the challenges in development of HSR in India.

4.1 Route Fixation (Origin, Destination and Intermediate Stations)

Route fixation would include selection of the first route, which should both be an economically viable[106] demonstration route as well as fit into a larger network vision. A distance of about 500 km between two major cities spanning a corridor with good economic development were the attributes of the first route in many countries including Japan, France and Korea. Apart from identifying the origin and destination of the route, the intermediate stations would also need to be decided. Fewer stations would provide for a faster journey time, while traffic catchment and political considerations may result in larger number of stations. High speed trains cannot stop at each and every intermediate station and HSR lines cannot reach every station en-route. But the demand for including growing cities and political demand to include more stations en-route is always there. In such a case, a service model consisting of a mix of non-stop trains and trains with fewer stops, as in Japan and Taiwan, may be worthy of consideration.

Competition for HSR would arise from air travel (for longer distances, say above 500 km), night travel by conventional rail (say between 500 to 1000 km) and road travel (for shorter distances, say below 200 km). Based on international experience, the sweet spot is often viewed in the 300 to 600 km distance, where there would be a significant edge over air, road and having the possibility of same-day return, thus scoring over conventional rail too. The 534 km Mumbai-Ahmedabad segment has been selected as the first route for HSR in India.

A second sweet spot, leveraging the preference for night travel, could be in the 1500-plus distance, where there could be high speed night travel. Having night travel would conflict with the traditional concept of doing maintenance by night in the HSR. However, it may be possible to explore mid-day maintenance schedules, when there would be a slack in demand.

At a micro-level, given the route choice, the alignment choice needs to consider environmentally-sensitive regions and protected archaeological sites, apart from other reasons that may influence land acquisition.

4.2 Choice of Technology Partner and Need for Standards

Given the state of research and development in India, it would be essential to go with another country with credible HSR experience as a technology partner. For the first route, Japan has been selected as the partner country. The question now would be the choice for further routes, whether we want to go with another partner to have

[105] (Shukla, Pathak, Mittal, & Dhar, 2015)
[106] (Prasad)

technological and commercial flexibility or wait and watch until the first route stabilises. This would have to be a strategic decision, since it has implications for long-term development.

Standards starting from the gauge width, the axle loading, the moving dimensions, the specifications of electric traction, track structure, etc. need to be finalised, again with a strategic perspective. Due to interoperability issues in Europe with a variety of signaling standards and systems, a 1996 European directive and a 2005 EU recommendation asked for member countries to adopt the European Rail Traffic Management System (ERTMS) as the control system for new lines, and to adapt existing ones.[107] The 25 kV AC standard for electrification has become almost universal.

A ballastless track, though with a higher initial investment, has a lower maintenance requirement, thereby allowing more availability of the track for operations.[108] The pre-feasibility report for the Ahmedabad-Mumbai-Pune route recommends an Indian broad gauge (1676 mm) ballastless track system. Rolling stock with a 3300 mm wide car body, and a 350 kmph operation speed was recommended. The traction choice was 25 kV AC. Major manufacturers of HSR rolling stock like Siemens and Alstom had responded positively to the possibility of developing broad gauge rolling stock.

With a poor safety record, the IR would need to take a big leap to a zero-fatality approach to safety in HSR. The pre-feasibility report of the Ahmedabad-Mumbai-Pune route has recommended ERTMS Level 2 for signaling and a full level of technical and operational interoperability with the existing IR network. Earthquakes and natural disasters would call for well thought-out emergency plans, including restoration of power, track and other critical aspects of the HSR system.

4.3 Location of Stations

The HSR stations may be located either in (i) existing railway stations at city centres, (ii) existing railway stations at the periphery of cities, or (iii) newly built railway stations at the periphery of cities.

While option (i) may be an ideal choice form the point of view of the catchment, peripheral locations would cost lesser and pose fewer problems in terms of land acquisition. However, seamless intermodal connectivity to the city centre is vital for good patronage of HSR. In this context, option (ii) would be preferred over option (iii), since local train services can be developed from the railway station in the periphery. In the case of option (iii), bus connectivity would have to be developed, unless the traffic demand would justify new rail construction to the HSR station, either for metro or local trains.

A long-term advantage of locating at the periphery would be potential expansion of the city and decongestion of the central business district.

[107] (Infrastructures and Stations, n.d.)
[108] (Systra, RITES, & Italferr, 2010)

4.4 Elevated versus Grade Level vs Underground System

Having a HSR at grade level would mean lower cost but also entails major problems to be overcome - land acquisitions and providing crossovers for roads and adequate protective fencing. It would divide geographies, putting a cost on those who need access from one side of the alignment to the other. Having an elevated ROW greatly minimizes the issues of land acquisition, road crossovers and fencing but it is quite expensive compared to the at-grade-level option. Aesthetics and dealing with existing structures could also be an issue. With an underground system, the problems of land acquisition, road crossover and fencing are completely avoided and aesthetics is not an issue. Existing structures could be an issue but they can be resolved. However it is the costliest of the three options. Across all the grade options, population densities, land values and topography will affect costs.

There are also constraints of curves and gradients. Tilting trains (Fiat Ferroviaria's technology) could be an option to deal with irresoluble curves in certain geographies. The pre-feasibility report for the Mumbai-Ahmedabad-Pune route recommends a minimum horizontal curve radius of 6425 m.[109]

4.5 Choice of Gauge and Interoperability of Trains beyond Core Networks

For HSR in India, it would be important to choose between the standard gauge (1435 mm) and the broad gauge (1676 mm), the latter being the conventional gauge in India. Most countries with HSR use the standard gauge, including those where this is not the conventional gauge, like Japan and Spain.

Adopting broad gauge for HSR would ensure interoperability of the HSR rolling stock on conventional rail, potentially increasing the catchment for the HSR trains. This would of course raise the issue of whether conventional rolling stock should be permitted on the HSR route, especially if there is scope for increasing capacity utilisation.

Adopting standard gauge would provide more scope for sourcing of rolling stock, through easy acquisition from other countries. Separation of service types by providing dedicated rights of way can improve reliability and capacity.

France, Spain and Japan have exploited interoperability by allowing high speed trains to run on conventional lines for increased connectivity. France could do it naturally, since the conventional lines had the same standard gauge. Spain came up with the gauge interchange system which changes the axle width. Japan has developed the concept of mini-Shinkansen, where certain stretches of the conventional narrow gauge has been converted to standard gauge to permit the high speed rolling stock, with customised narrower dimensions. Germany and Italy have interoperability both ways, i.e. high speed trains using conventional tracks and vice versa. In fact, they also permit freight trains to use the spare capacity of HSR in the night.

[109] (Systra, RITES, & Italferr, 2010)

Of course, in all these countries, a significant amount of interoperability is enabled through easy transfer between the high speed and conventional trains at many of the stations having both systems, through well connected infrastructure, ticketing and signage.

4.6 Pricing, Revenues and Funding

It would be important to arrive at the optimal pricing keeping in view competitive modes, perceived value of the HSR service (section 3.3.1), and the ability and willingness-to-pay of different market segments (section 3.3.2). Non-fare box revenues through station-related real estate development and commercial services for the rail user may also be necessary. It would be important to evolve a financial structure in keeping with the long-term gestation of such projects. In the case that these revenues do not make the project viable, government subsidies may be required and tied with non-transport benefits (technology percolation into other domains, economic development, game-changing sense of connectivity, and national pride due to cutting-edge infrastructure) that the project may bring in. Given the analysis behind financial versus economic viability, the institutional structure may be under a public-private-partnership mode or a government-owned engineering-procurement-contract mode.

The pre-feasibility report of Ahmedabad-Mumbai-Pune HSR estimated 12 million passengers in 2021, with pricing of INR 7 per km for first class and INR 4.50 per km for second class (75% of seats).[110] The economic internal rate of return of the project on Pune – Mumbai – Ahmedabad Corridor worked out to 12.8%. The first year (2021) return on investment is expected to be about 0.34%. This necessitates the need for Viability Gap Funding, if the project if implemented under public-private partnership. Findings by SNCF show a low internal rate of return of 2.4% over the life of the Mumbai-Ahmedabad HSR project, with recommendations of at least 50% of government funding and low fares for the line.[111]

According to OECD estimates, India's per capita GDP is expected to reach USD 5,000, in PPP terms, in 2020.[112] This corresponds to Japan's per capita GDP in 1965 when the first HSR service started between Tokyo to Osaka.[113] Initial fares could be lower for O-D segments not containing tier-I cities. Conservative forecasting of ridership would be important to avoid ambitious estimates of returns. Also, introducing of competitive public transport services in the same route as HSR must be avoided.

Where HSR operators practice revenue yield maximisation techniques (e.g. Eurostar, SNCF), the 'fill-up approach' boosts market share,[114] whilst also maintaining a high average fare through price discrimination, with the possibility of increasing both

[110] (Systra, RITES, & Italferr, 2010)
[111] ('₹90,000-cr Mumbai-Ahmedabad high-speed train project will have to be largely Govt-funded', 2014)
[112] (Shukla, Pathak, Mittal, & Dhar, 2015)
[113] (Shukla, Pathak, Mittal, & Dhar, 2015)
[114] (Preston, 2013)

commercial returns to the operator and benefits to users. Regressive distributional effects in benefits going to only high income group rail users due to high fares can be so addressed.[115] Middle-of-the-day journey schedules can charge much lower fares, comparable with those of intercity bus, to induce greater shift from other transport modes and maximise revenue.

Pricing and investment should be joint decisions.[116] At the roundtable, funding was acknowledged as the 'the main hurdle.'[117] High demand risk due to higher tariffs as compared to conventional rail could be mitigated by bundling of projects into smaller packages.[118] This could, however, increase operational complexity. Public funds, though limited in supply and cheaper when compared to private capital, have high opportunity cost due to potential use in socially more significant investments. However, Kumar (2014) says "financial viability, optimal resource utilisation and benefits to the people," are key issues to be more worried about.[119]

Apart from the bilateral financing option already being considered on the Mumbai-Ahmedabad pilot HSR route, supplier financing[120] could also be an option. Contribution of equity from state governments is justified as economic benefits of HSR accrue to regional areas and tier-II cities in the form of redistributive economic development.

A hybrid project model having (i) Engineering-Procurement-Construction (EPC) at low-interest bilateral funding for the construction phase, and (ii) Operate-Maintain-Transfer (OMT) during the operations phase, can be considered.

We have attempted below to estimate the average annual ridership needed in the Mumbai-Ahmedabad route for financial viability (Table 6).

- 80% (INR 781 billion) of the total INR 976.36 billion is taken to be funded by JICA at 0.1% interest with repayment starting in the 16th year of the 50 year repayment period. There are two risks associated with this funding: exchange rate risk and the requirement of using Japanese equipment and contracting. No monetary value has been attributed to this.
- The remaining 20% is assumed to be funded by the Government of India (GoI) with an expected 8% annual return during the operational phase.
- Annual financing costs would be INR 39 billion (INR 23 billion for the JICA loan and INR 16 billion towards GoI funds). The estimated daily financing costs for the route would be INR 106 million from the 16th year.

115 (Preston, 2013)
116 (Preston, 2013)
117 (Preston, 2013)
118 (Prasad)
119 (Kumar, 2014)
120 (Das, India must adopt broad gauge for high-speed rail: Siemens Mobility, 2015)

- An average fare of INR 1500 was taken for the route including O-D pairs containing two intermediate stops at Surat and Vadodara.[121]
- Taking two scenarios of operating ratios (ratio of operating costs to operating income) as 0.2 and 0.4, we arrive at a required annual ridership of 32 million and 43 million for the respective scenarios.[122]
- According to Ramakrishnan[123], the annual traffic that the Mumbai-Ahmedabad HSR would attract by 2025 is expected to be about 48 million, including those travelling for part of the route. He has considered the revenue-maximising rate as INR 5 per km. The total traffic across all modes estimated for 2010-11 was 62 million.

Annual financing costs (JICA) (INR billion)		23
Annual financing costs (GoI) (INR billion)		16
Annual financing costs (INR billion)		39
Daily financing costs (INR million)		106
Operating ratio	0.2	0.4
Average fare (INR) @ INR 5 per km and 300 km average lead	1,500	1,500
Fare towards servicing financing costs (INR)	1,200	900
Daily ridership required ('000 passengers)	88	118
Annual ridership required (million passengers)	32	43

Table 6: Estimation of Required Daily Ridership

5 Conclusions

The issues in developing a HSR network in India are complex. Given that India is a developing country, the primary concern is whether the funds for such a project could be better utilised in other domains, including in upgrading conventional rail. However, the Japanese funding to the tune of 80% of the project cost may not be available for other uses. The complexity of the project also arises due a variety of socio-economic implications like land acquisition, rehabilitation, and environmental concerns.

In spite of such complexity, there are many positive benefits and externalities of the HSR which would be useful in India's overall aspirational development. These externalities include technology percolation into other domains, economic development, game-changing sense of connectivity, and national pride due to cutting-edge infrastructure. In such a context, it is a good idea to begin and learn.

The Mumbai-Ahmedabad route is a good choice for the first route, since it connects India's first and seventh most populous cities, with significant economic development in the 500 km corridor between them. In terms of future network growth, this segment can be part of further extension to Jaipur and Delhi.

[121] (Ramakrishnan, 2015)
[122] (Ramakrishnan, 2015)
[123] (Ramakrishnan, 2015)

The low cost Japanese financing has been a great catalyst. Though it is a tied funding with significant mandatory procurement from Japan, it cannot do much harm since Japan is at the cutting edge of HSR technology with over 50 years of experience.

Acknowledgements

We thank the contributions of Shipha Gupta, Vamshidhar Reddy, Chirag Gupta, Rakesh Jinka, Anand Rathi, Niraja Shukla, Parakram Singh and Varun Jha in research and data collection.

References

(n.d.). Retrieved February 2, 2016, from High Beam: https://www.highbeam.com/doc/1P2-8871042.htm

'₹90,000-cr Mumbai-Ahmedabad high-speed train project will have to be largely Govt-funded'. (2014, November 24). Business Line. Retrieved February 8, 2016, from http://www.thehindubusinessline.com/economy/policy/90000cr-mumbaiahmedabad-highspeed-train-project-will-have-to-be-largely-govtfunded/article6630627.ece

About the Shinkansen: Safety. (n.d.). Retrieved February 5, 2016, from Central Japan Railway Company: http://english.jr-central.co.jp/about/safety.html

Chennai-Ernakulam High Speed Rail Corridor to be extended. (2011, October 30). Business Line. Retrieved February 7, 2016, from http://www.thehindubusinessline.com/economy/logistics/chennaiernakulam-high-speed-rail-corridor-to-be-extended/article2582767.ece

China Discovery. (n.d.). China High Speed Train Maps 2016. Retrieved March 28, 2016, from http://www.chinadiscovery.com/china-high-speed-train-tours/maps.html

Crozet, Y. (2013). High Speed Rail Performance in France: From Appraisal Methodologies to Ex-post Evaluation. Retrieved February 5, 2016, from International Transport Forum © OECD: http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP201326.pdf

Das, M. (2015, October 19). India must adopt broad gauge for high-speed rail: Siemens Mobility. Business Line. Retrieved February 2, 2016

Das, M. (2016, March 29). Japan hands out sweat deal for bullet train; beats expectations on soft loan terms. Business Line. Retrieved from http://www.thehindubusinessline.com/economy/logistics/japan-hands-out-sweet-deal-for-bullet-trainbeats-expectations-on-soft-loan-terms/article7980794.ece

Dastidar, A. G. (2016, March 27). India's 'fastest train' beats first Shatabdi by all of two minutes - See more at: http://indianexpress.com/article/india/india-news-india/indias-fastest-train-shatabdi-express-gatimaan-express/#sthash.9jH4NEQe.dpuf. The Indian Express. Retrieved March 27, 2016, from http://indianexpress.com/article/india/india-news-india/indias-fastest-train-shatabdi-express-gatimaan-express/

Delhi to Agra in 90 minutes flat. (2016, February 3). The Hindu. Retrieved February 3, 2016, from http://www.thehindu.com/news/cities/Delhi/delhi-to-agra-in-90-minutes-flat/article8181212.ece

Draft Report of Working Group on Railways Sector, set up by NTDPC. (n.d.). Retrieved December 13, 2013

eChinacities.com. (2014, December 11). New Harbin-Wuhan High Speed Rail Breaks Records. Retrieved January 28, 2016, from eChinacities.com: http://www.echinacities.com/news/New-Harbin-Wuhan-High-Speed-Rail-Breaks-Record

Effects of Korean Train Express (KTX) Operation on the National Transport System. (2005). Eastern Asia Society for Transportation Studies, 5, pp. 175-189. Retrieved February 9, 2016, from http://www.easts.info/on-line/proceedings_05/175.pdf

EFRTC. (2007). EFRTC Newsletter. Brussels: UNIFE. Retrieved February 3, 2016, from EFRTC: http://www.efrtc.org/htdocs/newsletters/Efrtc_Newsletter_2007_1.pdf

EuRail. (n.d.). AVE high-speed train. Retrieved MArch 28, 2016, from http://www.eurail.com/europe-by-train/high-speed-trains/ave

EuRail. (n.d.). ICE high-speed train. Retrieved March 28, 2016, from http://www.eurail.com/europe-by-train/high-speed-trains/ice

EuRail. (n.d.). Le Frecce high-speed train. Retrieved March 28, 2016, from http://www.eurail.com/europe-by-train/high-speed-trains/le-frecce

EuRail. (n.d.). Renfe-SNCF en Cooperación high-speed train. Retrieved March 28, 2016, from http://www.eurail.com/europe-by-train/high-speed-trains/renfe-sncf

EuRail. (n.d.). TGV high-speed train. Retrieved March 28, 2016, from http://www.eurail.com/europe-by-train/high-speed-trains/tgv

Garwood, M. (2014, November 21). EE and O2 now providing full 2G, 3G, and 4G access in Eurotunnel. mobile news. Retrieved February 6, 2016, from http://www.mobilenewscwp.co.uk/2014/11/21/o2-first-uk-operator-to-provide-full-network-access-in-eurotunnel/

Government becomes majority shareholder in Taiwan High Speed Rail Corp. (2015, July 28). Retrieved February 6, 2016, from Railway Gazette: http://www.railwaygazette.com/news/high-speed/single-view/view/government-becomes-majority-shareholder-in-taiwan-high-speed-rail-corp.html

Government takes control of London & Continental Railways. (2009, June 9). Retrieved February 6, 2016, from Railway Gazette: http://www.railwaygazette.com/news/single-view/view/government-takes-control-of-london-continental-railways.html

High Speed 1 concession awarded to Canadian pension consortium. (2010, November 5). Retrieved February 6, 2016, from Railway Gazette: www.railwaygazette.com/nc/news/single-view/view/high-speed-1-concession-awarded-to-canadian-pension-consortium.html

High Speed. (2016). Retrieved from UIC: http://www.uic.org/spip.php?article971

High Speed Rail Operations, Italy. (n.d.). Retrieved February 6, 2016, from railway-technology.com: http://www.railway-technology.com/projects/italy/

Honam high speed railway inaugurated. (2015, April 1). Retrieved February 9, 2016, from Railway Gazette: http://www.railwaygazette.com/news/high-speed/single-view/view/honam-high-speed-railway-inaugurated.html

Hsiu-chuan, S. (2011, July 26). Government to act on high-speed rail subsidence problem. Taipei Times. Retrieved February 9, 2016, from http://www.taipeitimes.com/News/taiwan/archives/2011/07/26/2003509173

HSRC. (2013). Formation of HSRC. Retrieved from High Speed Rail Corporation of India Limited: http://hsrc.in/backgroundFormationHSRC.html

HSRC. (2013). Objectives. Retrieved from High Speed Rail Corporation of India Limited: http://hsrc.in/objectives.html

Huang, J. (2009, November 11). Government takes charge at THSRC. Taipei Times. Retrieved February 6, 2016, from Taipei Times: http://www.taipeitimes.com/News/biz/archives/2009/11/11/2003458170

Hyo-sik, L. (2011, February 14). KTX causes safety concern. The Korea Times. Retrieved February 9, 2016, from Korea Times: http://www.koreatimes.co.kr/www/news/nation/2011/02/113_81386.html

Hyo-sik, L. (2011, May 11). KTX-Sancheon recalled after series of breakdowns. The Korea Times. Retrieved February 9, 2016, from http://www.koreatimes.co.kr/www/news/nation/2011/05/117_86847.html

ICE high-speed train. (2015). Retrieved February 5, 2016, from EuRail: http://www.eurail.com/europe-by-train/high-speed-trains/ice

ICE Train Accident in Eschede - Recent News Summary. (2000, February). Retrieved February 5, 2016, from NDTnet: http://www.ndt.net/news/2000/eschedec.htm

Infrastructures and Stations. (n.d.). Retrieved February 2, 2016, from ADIF: http://www.adif.es/en_US/infraestructuras/lineas_de_alta_velocidad/lineas_de_alta_velocidad.shtm

Kanwal, R. (2015, May 15). Exclusive: Is PM Modi's dream of a China-like high-speed rail model worth it? India Today. Retrieved March 31, 2016, from http://indiatoday.intoday.in/story/modi-china-visit-global-roundtable-super-fast-train-railways/1/437824.html

Korea Railroad Corporation. (n.d.). Domestic Business. Retrieved February 9, 2016, from KORAIL: http://info.korail.com/mbs/english/subview.jsp?id=english_020100000000

Korean Culture and Information Service, Ministry of Culture, Sports and Tourism; KOREA.net. (n.d.). High-speed rail contributes to balanced development: president. Retrieved March 28, 2016, from http://www.korea.net/NewsFocus/Policies/view?articleId=126653

KTX Is a Disaster Waiting to Happen. (2009). Chosunilbo, p. http://english.chosun.com/site/data/html_dir/2009/02/17/2009021761037.html. Retrieved February 9, 2016

Kumar, A. (2014, Ocobter 6). Bullet Trains, in perspective. The Indian EXPRESS.

LaFraniere, S. (2011, July 28). Five Days Later, Chinese Concede Design Flaw Had Role in Wreck. The New York Times. Retrieved January 28, 2016, from http://www.nytimes.com/2011/07/29/world/asia/29trains.html?_r=3

Ministry of Foreign Affairs, Republic of China (Taiwan). (n.d.). Infrastructure. Retrieved March 28, 2016, from http://www.taiwan.gov.tw/ct.asp?xItem=126574&CtNode=3770&mp=1

Ministry of Land, Infrastructure, Transport and Tourism, Japan. (n.d.). Railway Bureau: Shinkansen Japanese High-speed rail. Retrieved from http://www.mlit.go.jp/en/tetudo/tetudo_fr2_000000.html

New fares boost high speed traffic. (2014, March 21). Retrieved February 3, 2016, from Railway Gazette: http://www.railwaygazette.com/news/passenger/single-view/view/new-fares-boost-high-speed-traffic.html

NTV brands RFI access changes 'illegal'. (2011, March 25). Retrieved February 6, 2016, from Railway Gazette: http://www.railwaygazette.com/news/single-view/view/ntv-brands-rfi-access-changes-illegal.html

Okada, H. (n.d.). Features and Economic and Social Effects of The Shinkansen. Japan Railway and Transport Review(3), 9-16. Retrieved from http://www.jrtr.net/jrtr03/f09_oka.html

Pal, S. (n.d.). High Speed Rail in India: Selection of corridors and impact of emissions.

Penhaul, K., Maestro, L. P., & Smith-Spark, L. (2013, July 29). Spanish train driver charged in deadly crash. CNN. Retrieved February 3, 2016, from http://edition.cnn.com/2013/07/28/world/europe/spain-train-crash/index.html

Phillip Capital India Research. (2015). Infrastructure: All set for a robust FY16! Retrieved from http://www.phillipcapital.in/Admin/Research/76847983PC_-_Infrastructure_Sector_Update_-_June_2015_20150624104440.pdf

Planning Commission. (n.d.). EXECUTIVE SUMMARY: WORKING GROUP REPORT FOR XII PLAN - RAILWAY SECTOR. Retrieved from Planning Commission: http://planningcommission.gov.in/aboutus/committee/wrkgrp12/transport/report/wg_railway.pdf

Prasad, R. (n.d.). High Speed Rail – Challenges & Options: Indian Perspective.

Present Status of High Speed Rail Corridors. (2012, March 15). Retrieved February 8, 2016, from http://pib.nic.in/newsite/erelcontent.aspx?relid=80996

Press Information Bureau. (2016, March 1). High Speed Rail Corporations. Retrieved March 2016, 28, from http://pib.nic.in/newsite/PrintRelease.aspx?relid=137053

Preston, J. (2013, October). The Economics of Investment in High Speed Rail: Summary and Conclusions. Retrieved from International Transport Forum © OECD: http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP201330.pdf

PTI. (2016, January 8). Centre sets up panel to fix bullet train issues. The Economic Times. Retrieved February 8, 2016, from http://articles.economictimes.indiatimes.com/2016-01-08/news/69615333_1_bullet-train-bilateral-issues-panel

Raghuram, G. (2013). HSR in India. Retrieved from International Transport Forum: http://www.internationaltransportforum.org/jtrc/RoundTables/2013-High-Speed-Rail/India-Raghuram.pdf

Raghuram, G. (2014, April 28). High Speed Rail in India. Traffic Infra Tech Magazine. Retrieved from http://www.trafficinfratech.com/high-speed-rail-in-india/

Ramakrishnan, T. (2015, March 10). Modal Shift Estimation and Financial Viability of High Speed Rail in India: The Case Study of Ahmedabad-Mumbai Corridor (Doctoral Dissertation). Ahmedabad.

Rashid, A. (2013, March 11). Pune-Mumbai section dropped from high speed rail corridor plan. The Indian EXPRESS. Retrieved February 8, 2016, from http://archive.indianexpress.com/news/punemumbai-section-dropped-from-high-speed-rail-corridor-plan/1086191/

Shukla, P., Pathak, M., Mittal, S., & Dhar, S. (2015, September). Scenarios and Roadmap for Intercity Transport in India: The Role of High Speed Rail. Retrieved February 2016, from United Nations Environment Programme: http://www.unep.org/transport/lowcarbon/PDFs/Role_of_High_Speed_Rail_Final.pdf

Soni, A. (2013, October 29). Railway sets up High Speed Rail Corporation. Business Standard. Retrieved December 21, 2014

Systra, RITES, & Italferr. (2010). Pune-Mumbai-Ahmedabad High Speed Line: Final Report: Volume 0 - Executive Summary. Pre-Feasibility Study.

Taiwan high speed rail refinancing agreed. (2009, August 30). Retrieved February 6, 2016, from Railway Gazette: http://www.railwaygazette.com/news/single-view/view/taiwan-high-speed-rail-refinancing-agreed/browse/1.html

Taiwan, Taiwan. (n.d.). Retrieved February 6, 2016, from railway-technology.com: http://www.railway-technology.com/projects/taiwan/

Taiwan's high speed line takes off. (2007, November 29). Retrieved February 6, 2016, from Railway Gazette: http://www.railwaygazette.com/news/single-view/view/taiwans-high-speed-line-takes-off.html

Thales-Siemens JV bags Spanish High Speed Contract. (2015, August 26). Rail News. Retrieved from http://www.railnews.co.in/thales-siemens-jv-bags-spanish-high-speed-contract/

UK high speed rail map.png. (n.d.). Retrieved March 28, 2016, from Wikimedia Commons: https://commons.wikimedia.org/wiki/File:UK_high_speed_rail_map.png

What If There Is a Fire in a Railroad Tunnel? (2005, July 13). Retrieved February 9, 2016, from THE DONG-A ILBO: http://english.donga.com/List/3/all/26/241852/1

Wu, J. (2013). The Financial and Economic Assessment of China's High Speed Rail Investments: a Preliminary Analysis. Paris: International Transport Forum © OECD.

Appendix A: Identified HSR Corridors[124]

Identified HSR Route	**Distance (km)**	**Study type** Undertaken by whom (when) Report status (when)
Mumbai-Ahmedabad	505	**Pre-feasibility study** Systra, Italferr and RITES (commissioned in March 2009) Report submitted (April 2010) **Business Development Study** SNCF (France), as part of an MoU Report submitted (September 2014) **Feasibility study** JICA (October 7, 2013)

[124] Sourced from: R. Thakur/Live Mint (2013); PTI/Live Mint (2014); HSRC (2015); RailNews (2014); Philip Capital India Research (2015); Ministry of Finance, Govt. of India (2016)

		Report submitted (July 2015) and accepted by MoR **Memorandum of Understanding** Signed with Japanese government (December 2015)
Delhi-Chandigarh-Amritsar	450	**Pre-feasibility study** SYSTRA and RITES (October 9, 2014) Interim Report – II submitted (September 2015)
Hyderabad-Dornakal-Vijayawada-Chennai	664	**Pre-feasibility study** Japan External Trade Organisation (Japan), Oriental Consultants Co. Ltd. (Japan) and Parsons Brinkhoff (U.S.) Still in progress (June 2015)[125]
Howrah-Haldia	135	**Pre-feasibility study** Ineco, Prointec, Ayesa (all from Spain) Study completed. (2012)
Chennai-Bangalore-Coimbatore-Ernakulam-Thiruvananthapuram	850	**Pre-feasibility study** Consortium of Japan Railway Technical Service (Japan) and Oriental Consultants Co. Ltd. (Japan) Study in progress.
Delhi-Agra-Lucknow-Varanasi-Patna	991	**Pre-feasibility study** Mott McDonald (UK) Draft final report submitted. Study completed. (2011)
Delhi-Jaipur-Ajmer-Jodhpur	591	Tender to be finalized.
Diamond Quadrilateral (i) Delhi-Mumbai (ii) Mumbai-Chennai (iii) Chennai-Kolkata (iv) Kolkata-Delhi (v) Delhi-Chennai (vi) Mumbai-Kolkata	10,000	**Pre-feasibility study for (i), (ii) and (iii)** Consortiums awarded bids (September 2015) Package-1 (Delhi – Mumbai) by a consortium comprising the Third Railway Survey and Design Institute Group Corporation (China) along with Lahmeyer International (India). Package-2 (Mumbai-Chennai) by Systra (France), RITES (India) and Ernst and Young LLP. (UK) Package-3 (Delhi – Kolkata) by INECO, TYPSA and Intercontinental Consultants and Technocrats. (all from Spain) Studies in progress. **Feasibility study for (v)** Delhi-Nagpur section of Delhi-Chennai corridor taken up as Phase-I of government-to-government cooperation with China.

[125] (Phillip Capital India Research, 2015)

		China Railway SIYUAN Survey and Design Co. Ltd. (China) Planning study report completed.
Thiruvananthapuram-Kasargod-Mangalore	585	**Pre-feasibility study** Thiruvananthapuram-Ernakulam Delhi Metro Rail Corporation (DMRC) Report submitted (September 2011) **Pre-feasibility study** Thiruvananthapuram-Kasargod DMRC Report submitted (December 2011) **Feasibility study** DMRC (Survey 60% completed as on December 8, 2014) In Progress. (January 2016)