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High-Speed Rail: The Fast Track to Economic Development?

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Contents

Preface

This Report has been prepared for Mr. John Scales (jscales@worldbank.org), World Bank Transport Coordinator in Beijing, and under his guidance, by a consultant team consisting of Mr. Paul Amos, Mr. Richard Bullock, and Mr. Jitendra Sondhi.

The purpose of the Report is to disseminate information on China's high-speed rail development program, place it in the context of the history of development of high-speed rail internationally, and assess the lessons of international experience for countries contemplating the construction of high-speed lines.

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Disclaimer

Acronyms and abbreviations

AC	Alternating Current
AVE	Alta Velocidad Española
CBD	Central Business District
CRH	China Rail High-speed (trading brand for China Rail's high-speed services)
CNY	Yuan (or Rembimbi)
EMU	Electric Multiple Unit (train set)
HST	High-Speed Train
IPO	Initial Public Offering
JV	Joint Venture
km (s)	Kilometers
km/h	Kilometers per hour
MORC	Ministry of Railways of the Peoples' Republic of China
MLRNP	Mid- and Long-Term Railway Network Plan
pkm	A unit equivalent to the movement of one passenger by one kilometer
route-km	Kilometers of commercial railway route in network
RRA	A Regional Rail Administration of the MORC (also often termed a Railway Bureau)
SNCF	Société Nationale des Chemins de Fer Français
TGV	Train à Grande Vitesse
THSR	Taiwan High-Speed Rail, the trading brand of the high-speed railway in Taiwan, China
Ton	Metric ton of 1,000 kilograms
U.K.	United Kingdom of Great Britain and Northern Ireland.
TGV	Train à Grande Vitesse
U.S./U.S.A.	United States of America

Summary

Globally, there are about fifty purpose-built high-speed lines on which trains regularly travel with a maximum speed of 250 km/hr or more. In most cases they are dedicated high-speed lines. Nearly all of these lines have provided a quantum improvement in service level and travel time, as well as often providing a more direct route. Newer high-speed railways generally aim for 300 km/h or above – some Chinese, Spanish and French lines are designed for 350 km/h. Commercial speeds are typically around three-quarters of maximum speed.

A high-speed rail service can deliver competitive advantage over airlines for journeys of up to about 3 hours or 750 km, particularly between city pairs where airports are located far from city centres. One suitable type of corridor is that which connects two large cities 250-500 km apart. But another promising situation is a longer corridor that has very large urban centres located, say, every 150-300 km apart. On these longer corridors, typical of some being built in China, high-speed rail has the ability to serve multiple city-pairs, both direct and overlapping.

The demographic and economic conditions that can support the financial or economic viability of high-speed rail are limited. The established lines with greatest demand are in East Asia; the Tokaido line in Japan carries an average of 83 million passengers/year, and the Sanyo, Tohuku and Taiwan lines an average of 20-30 million passengers/year. In Europe, the French TGV SudEst and Atlantique lines both carry close to 20 million passengers/year. Nevertheless, high-speed projects have rarely met the full ridership forecasts asserted by their promoters and in some cases have fallen far short.

The overall financial performance of high-speed train services depends on enough people being able to pay a premium to use them. In Japan there is a surcharge for high-speed rail which doubles the fare on conventional services. China high-speed train fares are about three times conventional train fares. But in order to generate the required volume of passengers it will usually be necessary not only to target the most affluent travelers but also to adopt a fare structure that is affordable for the middle income population and, if any spare capacity still exists, to offer discount tickets with restrictions on use and availability that can fill otherwise unused seats.

Experience internationally is that construction and rollingstock capital costs, outside of China where they are significantly lower, typically range from USD 35 -70 million/km, depending on the complexity of civil engineering works, the degree of urbanization along the route and required total rollingstock capacity. Many projects have taken long periods to complete (over a decade is not unusual) creating a heavy capital and debt burden before any cash in-flows. Any delay in passenger ramp-up period, or shortfall in ridership or yield, can quickly create financial stress. Many lines internationally have run into trouble and had to have either restructure debt or seek additional funding from Government.

Operating and maintenance costs are generally low by comparison with the capital costs because speed delivers better equipment utilisation and train crew turn-rounds. Most lines at least recover their operating and maintenance costs. But is very difficult for most stand-alone high-speed railways to recover much of the capital costs from the passenger revenue stream alone, except in the very densest traffic corridors. Governments contemplating the benefits of a new high-speed railway, whether procured by public or private or combined public-private project structures, should also contemplate the near-certainty

of copious and continuing budget support for the debt. A developing country must reasonably expect at least 20 million passengers/year with significant purchasing power, just to have the possibility of covering the working expenses and interest costs of providing that capacity with high-speed service; and probably double that number of passengers to have any possibility of recovering the capital cost.

High-speed lines will naturally provide valuable travel time savings to users and may also free up capacity on existing lines for other transport users and enable performance improvements on those lines due to lower congestion. It may also affect the relative usage of different modes of transport creating resource savings if those other modes have higher unit costs of operation. High-speed rail will also have various environmental and social consequences that may on balance be negative or positive. A high-speed passenger train will use more energy, and thereby generate more greenhouse gases, than a slower passenger train over the same route. But if the higher speed attracts passenger travel away from road and air it may reduce the overall long-term carbon intensity of the transport system as a whole. Through mode transfer it will also reduce road congestion and accidents. Fundamental changes in accessibility and mobility are also likely to influence regional economic development but these are the hardest effects to predict and quantify.

In summary then, high-speed rail is now a tried and tested technology that delivers real transport benefits and can dominate market share against road and airline transport over the medium distances that many inter-city travelers confront. However, the demographic and economic conditions that can support the viability of high-speed rail are, in global terms, limited. The number of passenger transport corridors of the requisite length, that are already capacity constrained, and where there is sufficiently dense potential demand by people of adequate purchasing power, is limited; some may be in countries where the implementation capacity may be lacking.

The combination of supportive features that exist on the eastern plains of China includingvery high population density, rapidly growing disposable incomes, and the prevalence of many large cities in reasonable proximity to one another (creating not just one city-pair but a string of such pairs) are not found in most developing countries. Nor could all countries assemble the focused collective capacity-building effort and the economies of scale in construction costs that arise when a government can commit the country, politically and economically, to a decades-long program over a vast land area. Even in China, the sustainability of railway debt arising from the program as it proceeds will need to be closely monitored and payback periods will not be short, as they cannot be for such “lumpy” and long-lived assets. But a combination of those factors that create favorable conditions of both demand and supply comes together in China in a way that is distinctly favorable to delivering a successful high-speed rail system.

1. A new milestone in passenger train travel

The 2010 Spring Festival was a few days away, and the Chinese people were getting ready to celebrate their most important holiday of the year. This year, they had something significant to celebrate ahead of the eagerly anticipated festivities of the Lunar New Year: China's first 350km/h plus, high-speed train had set out on its 1,068-kilometer journey from Wuhan to Guangzhou. Hurtling along a new, dedicated track that cost the equivalent of USD 17 billion, it was not a long journey; the sleek, ghost-white trains of China's high-speed railway service (branded "CRH") can deliver passengers between these cities in just three hours, a journey that used to take the best part of half a day.

Remarkably, when it is complete the Guangzhou to Beijing line alone will catapult China ahead of France's entire TGV high-speed network, in terms of length of route operated. Even more remarkably, China's high-speed rail revolution has hardly begun. By 2012 China will have built no less than 42 passenger lines with maximum train speeds in excess of 250km/h, and will offer high-speed rail travel on 13,000 kilometers of route. China will have more high-speed railway than the rest of the world put together.

It is appropriate that the passing year should have been the Year of the Ox, a creature that symbolizes hard work and tenacity. For it is these values, in combination with technical excellence, that have been instrumental in bringing China's vision for a high-speed rail network to fruition. It is also appropriate that the new lunar year is the Year of the Tiger, which symbolizes hope for the future.

China hopes and expects its high-speed railway to be a success; but how transferable is this hope? Several countries including Brazil, India, Russia, Turkey, the United Kingdom and the United States are contemplating the merits of investing in high-speed rail. What can they learn from China's experience? How does China's system compare with other existing high-speed railways in the world? Why are high-speed railways an issue of development significance, and what are the circumstances in which they can become an economically justifiable investment? This paper briefly explores these questions.

2. The story of high-speed rail

Fast passenger trains have been around for many decades. They originally ran on conventional railway lines, limited by sharing track with slower passenger and freight trains. The speed record for a steam locomotive was set in the United Kingdom by the locomotive, Mallard, at 203 km/h in 1938.[1] It is thought that several U.S. steam locomotives were also capable of similar speeds (e.g. on the Chicago-Milwaukee service) but this was not trumpeted for fear of scaring the passengers. Multiple-unit trains, which are trains made up of power units and passenger cars combined in a fixed formation, have also been running at fast speeds since the Flying Hamburger in Germany in 1933, which travelled at a top speed of 150 km/h and a commercial speed[2] of 130km/h, despite the limitations of running on conventional track, with curves, station limits and so on.

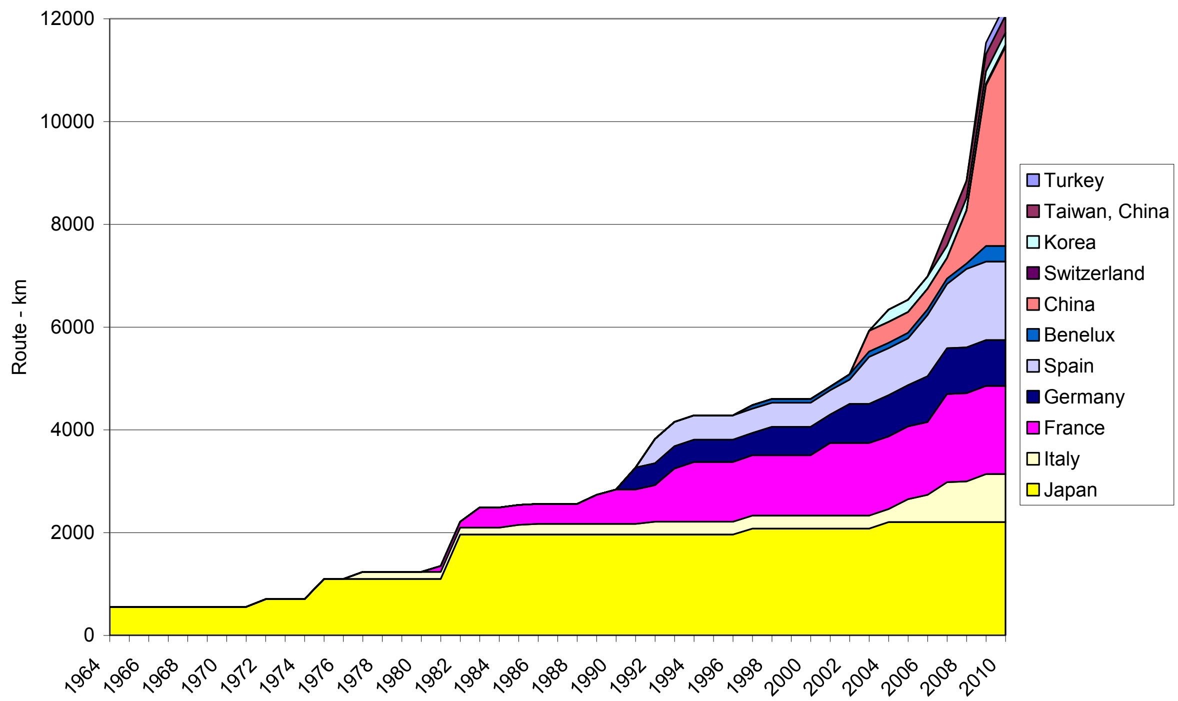
The modern era of fast train travel (charted in Figure 1 below) opened in the 1950s in Japan. The conventional, mixed-use (passenger and freight) line between Tokyo and Osaka had become very

[1] Albeit for about half a mile after a period of downhill running.

[2] Commercial speed is derived by dividing the distance by the total time of the journey, including station stops.

congested. More capacity was needed. As part of a project partly financed by the World Bank, it was decided not to provide additional capacity in the conventional manner of multiple-tracking the line. Instead, Japan built a new 515 kilometer-long, passenger-dedicated, electrified high-speed line on a new alignment. Construction began in 1959, so that the service could open in time for the 1964 Tokyo Olympics.

Figure 1. Route-km of high-speed line by country and year



This Tokaido Shinkansen, or bullet-train, delivered a quantum improvement in travel time within a year through a maximum speed of 210 km/h and an average commercial speed (including two intermediate stops) of over 160 km/h. Significantly, it also offered a much higher frequency of service. The number of express trains between Tokyo and Osaka was increased on opening, from four each day to an hourly service. By 1970, with substantial traffic growth, the frequency had tripled to three trains per hour.[3] This first route was a financial success. By 1967 revenue exceeded operating costs, including interest and depreciation.

The success of the Tokaido Shinkansen led to the adoption by the Japanese Government of the Shinkansen Development Law in 1970. The law set out a blueprint for a high-speed network of some 7,000 route-kms. The system was steadily extended, to Fukuoka in Kyushu (1975); to Morioka in northern Honshu (1982); and to Niigata on the west coast (1982). Subsequent extensions have seen the

[3] Stopping trains were also operated, hourly in 1964 and three per hour in 1970.

network reach its current size of nearly 2,200 route-kms. Speed has also increased: the Tokyo-Osaka service now has a commercial speed of 200 km/h (typically with four intermediate stops).

These developments in Japan were watched closely in Europe. The next passenger services capable of operating at over 200 km/h[4] were British Railways' (BR) HS125 diesel-electric multiple unit trains that commenced operations on the mixed-use Great Western line from London to Bristol in 1976.

Across the Channel, the French National Railway (SNCF) was faced with the need to provide extra capacity on the busy main line between Paris and Lyon. But SNCF also wanted to be able to offer faster services and decided to adopt the Shinkansen approach of building a dedicated line on a new alignment. SNCF initially thought of using gas-turbine locomotives and successfully tested a prototype, but the rising price of oil led it to adopt electric traction. In 1981, the TGV Sud-Est opened between Paris and Lyon and was followed, between 1985 and 2007, by other lines: to south-western France (TGV Atlantique); to southern France and Switzerland (TGV Méditerranée and TGV Rhône-Alpes); to northern France, Belgium and Holland (TGV Nord); and to eastern France and Germany (TGV Est). France now has a high-speed network of nearly 1,700 route-kms.

Other European countries have since followed suit. New lines have opened in Spain, Germany, Italy, Belgium, the Netherlands and the United Kingdom. Currently in 2010, the total length of dedicated high-speed lines in Europe is 5,500 kms. With the benefit of both Japanese and European experience high-speed lines have also been built in Taiwan, China (the THSR system) and in Korea. The THSR, between Taipei and Kaohsiung, opened in 2007. The Korean line, linking Seoul and Busan, was opened as far as Daegu in 2004 with the line expected to be completed by the end of this year. Extensions are planned, but both lines are relatively short. The total global length of high-speed line is estimated[5] (as at April 2010) at nearly 12,500 km.

In recent years, mainland China has taken its place on the international stage of high-speed rail, and is already dominant in terms of system length and utilization.

3. China's high-speed rail system: from vision to delivery

The Ministry of Railways (MORC) is creating what will be by far the biggest network of high-speed (250km/h plus) services in the world. High-speed train travel did not just appear in China overnight, however. MORC has for three decades faced the challenge of how to meet growing freight and passenger demand and prevent railways from becoming a bottleneck on development. It progressively discouraged short-distance freight and passenger travel, to divert this demand to road transport while expanding medium- and long-distance capacity. As a result, the average distance travelled by passengers on the national railway system nearly doubled, from 275 km in 1990 to 534 km in 2008. On the freight side China Railway adopted many initiatives to help handle more freight, but even so there is substantial unmet demand for rail freight transport on many routes.

[4] In 1973 a prototype had set a world speed record for a diesel locomotive, of 230km/h.

[5] For the purposes of network length estimates, high-speed lines have been taken as those with services of 250 km/h or more. Most are dedicated, purpose-built passenger lines but a few are parallel to existing alignments, and some also carry lower-speed freight services. Several services (e.g. the TGV in France) start and finish their journeys over conventional lines; these distances have been omitted.

Measures to increase passenger train speeds were initiated in the mid-1990s. The focus was on gradually increasing speeds on existing routes, while also developing China's know-how in all facets of faster rail infrastructure and train operations. Between 1997 and 2001 the maximum speed of conventional trains operated with locomotives was increased from 100 km/h to 160 km/h on around 13,000 km of passenger routes. A trial section of about 60 kms of high-speed line was opened in 2003 between Qinhuangdao and Shenyang and was used to test various track designs and EMU alternatives for even faster trains.

The Guangshen Railway Company was the first to introduce very fast trains in China. Created as a subsidiary of the Guangdong Regional Rail Administration, the company had been listed on the Hong Kong and New York Stock Exchanges as early as 1996. In 2004, the company began operating trains between Guangzhou and Shenzhen at a maximum speed of 200 km/h.[6] Following that success China Rail introduced express electric multiple unit trains, with a maximum speed of 200 km/h, on 16,500 km of track.

In 2007 140 train pairs per day, operating at top speeds of 200-250 km/h, were launched on over 6,000 kms of mixed-use routes. The services (by now branded "CRH" and increasing in number) are currently operated with modern, air-conditioned eight- and 16-car EMU train sets and have a commercial speed of over 150 km/h. First class accommodation has two-by-two reclining seats, while second class features a two-by-three seat configuration. The general ambience and riding quality of these trains is world-class and they have proved very popular, even though the price charged is substantially higher than on normal express trains.

These progressive enhancements to speed and performance were enabled by corresponding advances in the standards and management of railway sub-systems, including track and track formations; train dispatching and control; telecommunications; electric traction; motive power; rolling stock; and train operations. This 'speed-raising' program, although built around the use of conventional lines, both required and reinforced a growing technical competence in all these areas. It nurtured an increasing confidence on the part of railway professionals in their ability to take the step towards dedicated high-speed passenger rail operations.

At the same time a massive effort was launched to learn about the high-speed rail technologies available internationally, to select those most suitable for use in China, and to adapt them to local conditions. The separation of rolling stock manufacturing units from MORC in 2000 facilitated the participation of international manufacturers in joint ventures with Chinese counterparts, and this gave China Rail access to modern traction technology over a relatively short period. The international joint venture partners helped capitalize modern manufacturing plants and transferred know-how in the design and manufacture of modern train sets.

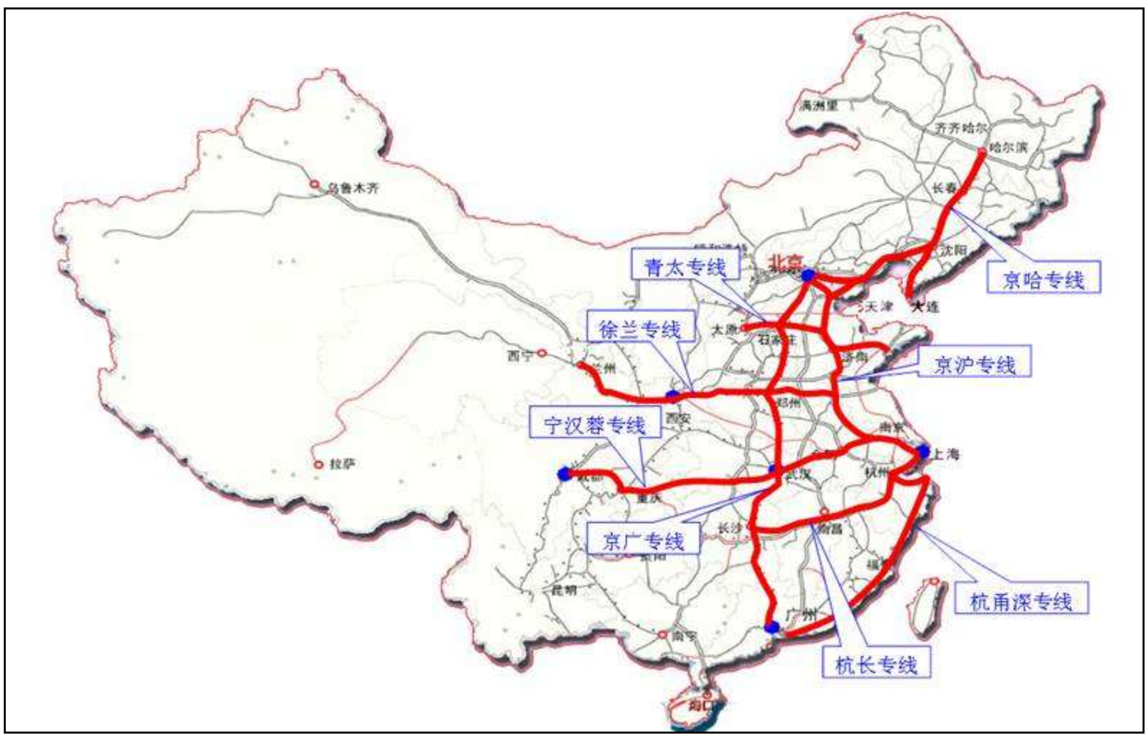
Two or more joint ventures were typically established for each product. For example, each of the four major international manufacturers of high-speed electric multiple unit trains has a joint venture with a Chinese counterpart; contracts for 200 EMU train sets for 250 km/h and 350 km/h operation were

[6] It now operates about 80 pairs of trains per day, or a train every 15 minutes between Guangzhou and Shenzhen.

awarded to these joint ventures. MORC has declared long-term plans for CRH's procurement of a relatively large volume of EMUs in the period to 2020, a strategy that encourages multiple suppliers to prepare and compete for future high-speed train business.

In 2003, for the first time, full details of the planned network of dedicated high-speed routes were unveiled in MORC's Mid to Long-Range Network Plan (MLRNP. The Plan, the first industry plan of its kind approved by the Government of China, comprehensively addressed the future development of the railway network in all its facets. The crucial decisions in the Plan were to separate passenger and freight services on constrained trunk routes, and to develop fast inter-city regional passenger networks in densely populated areas. The separation of freight and passenger services is being achieved by building passenger-dedicated lines on which services will operate at top speeds of between 250 and 350 km/h (depending on the route). The Plan originally targeted a 12,000 kms high-speed passenger network by 2020, based on four north-south and four east-west corridors, plus a further 20,000 kms of mixed traffic high-speed lines with a target speed of 200-250 km/h. The Plan (as augmented in 2007) is shown in Figure 2.

Figure 2. Planned dedicated high-speed passenger line network 2020 (MLRNP)



The stimulus package launched by China in 2008 to mitigate the impact of the global financial crisis has more than doubled the investment funds available for railways for the years 2008 to 2010, enabling

MORC to accelerate the construction of the high-speed rail network.[7] As a result the completion dates of several projects were brought forward, and it is now planned to complete construction of 42 high-speed rail lines by 2012, amounting to 13,000 route-kms. Of this, 8,000 kms will have a maximum speed of 350 km/h while 5,000 kms will have a maximum speed of 250 km/h. According to the latest projections of MORC, by the year 2020 16,000 km of high-speed railways will connect all of China's provincial-level capitals and cities on the mainland that have more than 500,000 residents, and serve more than 90 percent of the population. High-speed train services will be operated by the national railway that the Ministry administers, China Rail,[8] under the specific brand of CRH or China High-Speed Rail.

Funding for China's high-speed rail network is difficult to isolate from the sources of overall investment in the railway sector. In 2007, nearly half of rail investment was funded from domestic bank loans and bonds, about 16 percent from provincial governments and public enterprises (through use of the joint venture model), and about 15 percent from a construction surcharge on freight. Since 2007 the overall program has expanded substantially, there has been a 10 percent increase in the construction surcharge, and other funding sources have been developed; so 2007 may not constitute an accurate picture of the final outturn.

China's high-speed rail network is a huge undertaking: it is perhaps the biggest single planned program of passenger rail investment there has ever been in one country. But the benefits of the new network of services will not accrue only to its passengers. Just as importantly, the new high-speed lines will release much-needed capacity for growing freight traffic on China's existing lines.[9] MORC believes that the high-speed rail network of China, in which it is investing around CNY 2 trillion (or USD 300 billion), will help make China even more economically competitive and connect the disparate regions of this vast country as never before, much as the building of the Interstate highway system transformed national transport cohesion in the USA a half-century ago.

High-speed rail is also about winning the competition with other transport modes. Fittingly then, the first 300-350 km/h speed train, on a dedicated high-speed passenger line, opened on the Beijing-Tianjin corridor to coincide with the Beijing Olympic Games.

High-speed operation requires relatively straight track with large radius curves, so building high-speed lines on existing alignments (through populated urban areas) often displaces and requires the resettlement of large numbers of people. The dedicated high-speed passenger lines are therefore being built on new alignments, and most new stations are being built on the outskirts of cities with good road connections and in some cases new metro rail lines to the CBD. Initially the interval between trains will be 10-15 minutes, but the system is capable of running trains with headways of 5 minutes if demand should require it.

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[7] MORC invested USD 49 and 88 billion in 2008 and 2009 respectively, against USD 26 billion in 2007. It is planning to invest a further USD 100 billion in 2010.

[8] In practice administered by 18 Regional Rail Administrations and a number of other specialised entities.

[9] The inference that use of funds from the construction surcharge on freight is being used to cross-subsidise passenger lines may be tempered by the fact that one of the major financial benefits of the new lines is their release of capacity on the existing lines for freight.

Construction of dedicated high-speed passenger lines is proceeding in several new corridors simultaneously. The Guangzhou-Wuhan-Zhengzhou-Beijing line (2,100 km) is being built in four sections. The construction of the southern section, Guangzhou-Wuhan (1,068 km), started in June 2005 and, as noted in Section 1, opened in early 2010 at a cost equivalent to about USD 17 billion; the trains on this section have a top speed of 394 km/h. Non-stop trains on this line travel at an average commercial speed of 350 km/h, significantly faster than in Japan and France. The remaining three sections of Beijing-Guangzhou, between Beijing and Wuhan (1,100 km), are scheduled for commissioning in 2012. Other dedicated high-speed passenger lines under construction include the Beijing-Shanghai line, where construction began in early 2008 and is expected to be completed by 2011. It is estimated that as many as 110,000 to 120,000 workers are engaged in building the line, which will cost an estimated USD 33 billion. The terminal-to-terminal time will be reduced from ten to about five hours.

CRH train sets are modern, high-speed AC drive EMUs. Of 200 train sets on order with four manufacturers, 105 sets of eight-car trains were delivered in 2007. They use high-strength aluminum alloy body shells weighing 8.5 tons, and they will be serviced at four main depots at Beijing, Shanghai, Wuhan, and Guangzhou. China plans to procure about 1,000 EMU train sets by 2015.

Several foreign firms helped China to manufacture state-of-the-art trains. Bombardier-Sifang, a joint venture between Canadian and Chinese manufacturers, won a USD 4 billion contract in September 2009 to produce 80 train sets with a new energy-efficient system for propulsion and control. Siemens is involved in a similar deal, worth around USD 1 billion. Kawasaki Heavy Industries is licensing a Chinese firm to build 140 of its trains, for USD 6 billion. Alstom, Hitachi and others have also secured business. This transfer of technology and know-how, together with the experience of building and operating several thousand route-kilometers of high-speed railway, will make China's one of the most advanced railway industries in the world. This should position the country to compete internationally when other countries adopt high-speed railways. It is reported, for example, that U.S. Company General Electric and MORC have pledged to strengthen their cooperation in the United States for delivery of high-speed rail projects.

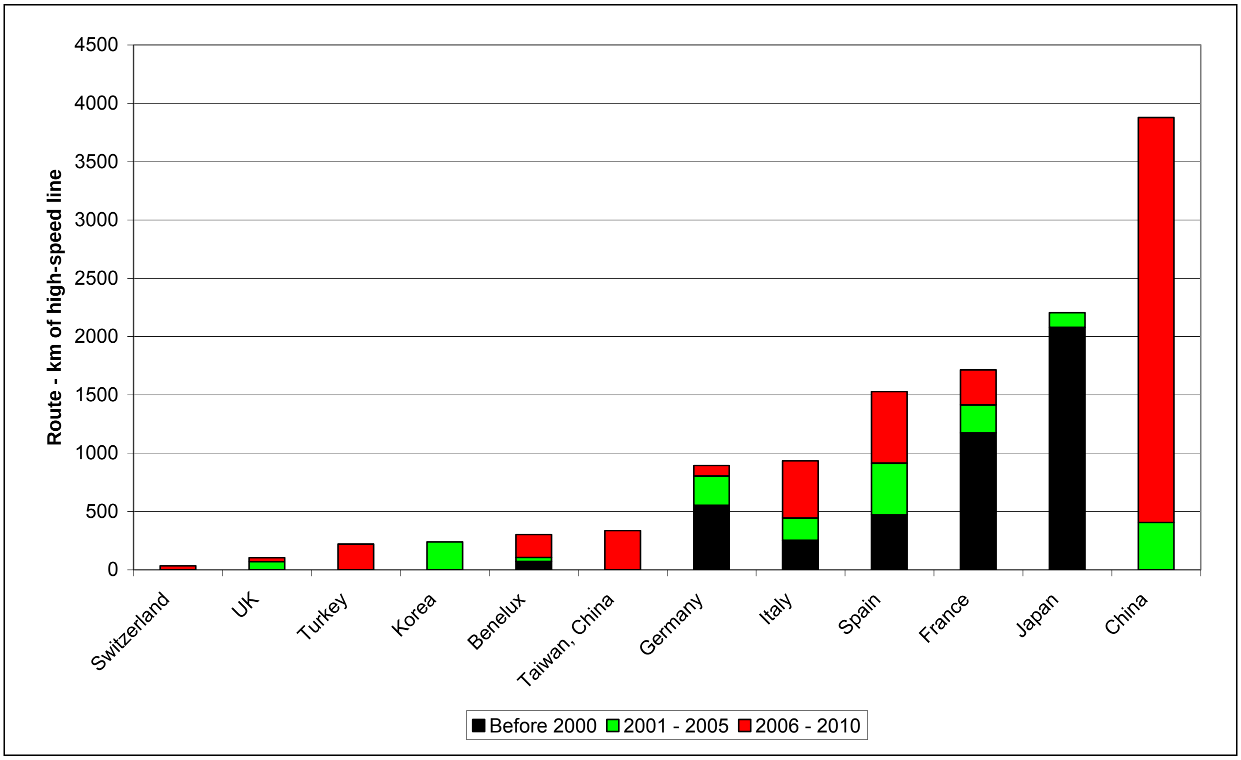
4. System performance

There are engineering and technology differences between high-speed railways in different countries, but for the transport planner or policy-maker the general parameters of interest are operational performance, market performance and financial impact.

Currently (April 2010), there are about 50 purpose-built high-speed lines on which trains regularly travel with a maximum speed of 250 km/hr or more (Figure 3). In a few cases these lines are shared with lower-speed passenger or freight trains, but in most cases they are dedicated high-speed lines. There are also several instances where high-speed services continue into city centers on conventional lines running at reduced speeds.

In almost all 50 cases, these lines have provided a quantum improvement in service level and travel time, as well as often providing a more direct route. Before the initial high-speed railway in Japan between Tokyo and Osaka (the Tokaido Shinkansen) opened, an EMU service was operating with a commercial speed of 85 km/h and a travel time of nearly seven hours. Although the initial Shinkansen service had a commercial speed of about 125 km/h, this was quickly increased. Within a year the travel time had been reduced to just over three hours; this has steadily improved over the years, and the commercial speed for the fastest services is now just over 200 km/h with a maximum speed on this line of 270 km/h. Other high-speed railways (including subsequent high-speed lines in Japan) now generally aim for 300 km/h or above; some Chinese, Spanish and French lines are designed for 350 km/h.

Figure 3. High-speed line by country (April 2010)



Trains on most lines are around eight passenger cars, although these are increased to 16 cars on the more heavily used routes, such as in Japan and China. Capacity averages 50 to 70 passengers per car, depending on the on-board services and the split between first and second classes. Train capacities are thus normally 400 to 500 passengers in Europe, but over 1,000 in Asia when longer trains are used.[10] Double-deck cars are used in France, which also has special fast trains for mail and parcels.

Few high-speed lines operate at less than an hourly frequency, with most much less frequent than that. Departures are obviously more frequent on more heavily used lines. On the Taiwan, China line, there are 56 services daily. On the Beijing to Wuhan line in China, open only three months ago, there are already 21 services each way daily. The TGV Sud-Est has about 30 services each weekday; the Madrid-Barcelona has 27 services. Frequency is invariably better than it was before. As already noted, four limited EMU express trains daily in each direction were replaced on the Tokaido Shinkansen line by an initial service

[10] THSR operates 12-car trains with a capacity of 989 seats; China (on Wuhan-Guangzhou) operates 16-car trains with a capacity of 1,100-1,220 seats; Korea operates 10- and 20-car trains with a capacity of 363 seats per 10-car train (KTX2 model); and Japan (on the Tokaido/Sanyo lines) operates 16-car trains with a capacity of 1,323 seats.

of 26 train pairs daily (one express and one stopping train each hour in each direction), which has now increased to 119 pairs per day.

High-speed services are typically reliable and keep to schedule. The Japanese service is well ahead of any other, with an average delay on the Tokaido line of only 0.6 minutes per trip. Most other systems also perform well, although not to this standard. Those that only use dedicated tracks do better, whereas some European systems, particularly the German ICE network, use conventional lines for significant journey sections.

Convenient access is usually provided to railway stations with improved accessibility by road or metro-rail, and efficient interchange arrangements to cater to large volumes of passengers in peak hours. In some countries stations have been designed or redesigned on airport lines, separating the arriving and departing passengers and providing comfortable service and waiting areas.

Safety is generally very good. Japan is again the clear leader, with no fatalities since the services began over 40 years ago. France likewise has had no fatalities, although it has had a number of derailments.[11] The worst accident involving a high-speed train was on the German ICE system, when the metal tire of a wheel broke off, leading to 101 deaths. However, the accident actually occurred while the train was using a conventional line at 200km/h, and the wheel was not of a conventional high-speed rail design. In overall terms the high-speed rail safety record is hugely better than that of road transport, and compares favorably with air transport.

Moving from operations to markets, high-speed rail has invariably increased the demand for rail travel even when fares have been set at much higher levels than those for conventional rail. Reductions in travel time of one-half or two-thirds are not uncommon and this, combined with better service frequency, has boosted demand. This has partly come about by capturing trips from other modes, especially from air transport for journey times (by rail) of about 3 hours. New trips have also been generated that were not made before. Finally, the time savings mean that the opportunities provided by trips of, say, one hour by high-speed train have expanded the catchments of major urban centers and altered patterns of regional travel.

However, not all users of high-speed trains necessarily have very high values of time savings. In some countries competing conventional services have been curtailed, inducing use of the new high-speed service by some travelers who might have preferred to use a slower service at a lower price. In others, ticketing systems are used to offer lower fares to those passengers without high time values, to fill up seats at non-peak times. Once a high-speed train is available it makes sense to use yield and capacity management techniques to utilize it fully. It is therefore not entirely accurate to characterize high-speed rail simply as an exclusive service for premium passengers. As in the case of the introduction of wide-bodied jets, the huge increment of capacity offered by a new high-speed railway line offers the opportunity, indeed the necessity, of attracting a wide range of sub-markets.

Nevertheless the overall financial performance of high-speed train services broadly depends on enough people being able to pay a premium to use them. In Japan there is a surcharge for high-speed rail, which

[11] On the high-speed lines; TGV trains have been involved in two fatalities at stations on conventional lines.

doubles the fare on conventional services. In the United Kingdom, the high-speed line between the Channel Tunnel and London also carries a long-distance commuter service, which reduces trip time by 40 percent compared to the conventional route but has a fare 20 percent higher. On most of the longer lines internationally, the competing air fare is a major factor in setting rail fares. In some, the railway fare structure mimics the pattern of fares available on the airlines and as a result, prices vary greatly depending on the flexibility of the ticket and how far in advance it is purchased. Typical fares in France and Spain are around US$0.10 per passenger-km (pkm) but are typically rather more, up to double, in northern Europe. The average yield in Japan is about US$0.25 per pkm but elsewhere in Asia it is typically US$0.10 per pkm.

In China, the three-hour high-speed rail journey between Wuhan and Guangzhou costs the equivalent of USD 72, against USD 21 on a conventional train that takes about 10 hours. As might be expected many passengers still prefer the slower, cheaper alternative, but transfer to high-speed is expected to increase steadily as incomes increase and more people try the new service for the first time. Recognizing that virtually all major transport projects, including the original Shinkansen, involve significant demand ramp-up periods, MOCR believes that with the expected rise in China's income levels over the next five to 10 years it will have no problem in filling CRH seats. Certainly China's airlines agree, and have expressed grave concerns for the future of short-haul air travel. Nevertheless, at the present fare levels, whilst high-speed rail will be a major competitor for the higher end of the market in China, a substantial part of the present long-distance rail market in China will find travel by high-speed train an expensive proposition. It seems likely that yield management techniques will need to be introduced to attract passengers who can fill seats at less busy times and at fares less than the full-premium price.

Internationally, the established lines with greatest demand are in East Asia; the Tokaido line carries an average of 83 million passengers per year,[12] and the Sanyo, Tohuku and Taiwan, China lines an average of 20 to 30 million passengers per year. In Europe, the TGV SudEst and Atlantique lines both carry close to 20 million passengers a year, but elsewhere in Europe ridership is much lower at between 5 and 10 million passengers per year.

All high-speed rail services have improved the market share of railways on the routes where they compete. In a few cases, competing short-haul air services have been withdrawn entirely and in others most of the air travel remaining consists of interlining traffic between provincial and international airports. In Germany even the interlining market has been partially captured by railways, through the practice of airline code-sharing with a high-speed rail service (such as between Frankfurt Airport and Cologne-Bonn Airport). High-speed rail services have made major inroads into any competing coach service markets even though the high-speed rail tariffs are generally significantly higher than the coach fares. It has also captured passengers from private cars, although this is a more complex market where mode choice depends on many factors such as travel group size, quantum of luggage, and company car

[12] This is the average density over the route; the total number of passengers in 2009 was 149 million but many are travelling to and from intermediate stations.

ownership. Generated trips have usually been found to be significant, although not always easy to define and capture in surveys. [13]

In Japan, around 50 percent of the initial ridership transferred from conventional rail with the remaining 50 percent either transferring from other modes or being newly generated. The impact on air services was severe, with a number of shorter-distance routes being terminated and air losing upwards of 70 percent of its traffic on the shorter-distance routes. In France conventional rail services had a 30 percent share of the air/rail market on the Paris-Lyon route prior to the introduction of the TGV Sud Est; currently almost all (estimated at 97 percent in 2008) domestic traffic goes by rail. About 20 percent of rail passengers had transferred from air, 15 percent from car and the remaining 35 percent were generated trips. For main centers such as Lyon, the gains from air transport were larger, with air travel demand reducing by over 40 percent.

In Germany, about 65 percent of the early high-speed ridership came from other rail services, with about 20 percent of the new traffic reported to be from car, 15 percent from air and a small amount generated.

The first Spanish line from Madrid to Seville reduced the travel time by rail between the two cities from around 6 hours to 2.5 hours. Conventional rail had had a 20 percent market share, with car having 50 percent and air and bus having 20 percent and 10 percent respectively. Rail market share reached about 40 percent after the first two years of high-speed operation by the AVE service, of which about 30 percent was generated, 25 percent transferred from car, 30 percent from air, 13 percent from conventional rail, and 2 percent from coach transport.

The general experience is that rail has 80 percent or upwards of the market at 500 km, reducing to 20 percent or so for a 1,000 km trip, and that 20-30 percent of the HSR demand has been generated, i.e. consists of trips that were not made prior to the introduction of the service. Similar results have been found from surveys of conventional rail, with around 20 percent of the increase in traffic as a result of fare reductions coming from generated rather than transferred traffic. A detailed survey done when Eurostar (London-Paris) was first introduced confirmed this, with around 25-30 percent of the total ridership consisting of generated trips.

What is also clear is that the connectivity of stations to access and egress modes is an important consideration in attracting ridership to high-speed rail, especially where stations have been built in relatively isolated locations on new alignments. Without fast and frequent connecting services, the advantages of high-speed line-haul travel can be eroded. In addition, high-speed rail operators also need to factor into their revenue projections the competitive response of other modes such as budget airlines, which can significantly reduce the average revenue yield per passenger compared to the full premium fare.

[13] For example, much of the early TGV forecasting work referred to “generated” trips as all trips which did not divert from conventional rail or air (typically the only modes for which the forecasters had data).

Figure 4. The new Wuhan CRH Station, China.

Despite the clear success of high-speed rail in increasing ridership and improving market share, even a good story can be oversold. High-speed projects have rarely met the full ridership forecasts asserted by their promoters, and in some cases have fallen woefully short (such as the forecasts for the Eurostar services between London and Paris and Brussels). A whole new area of behavioral research has been generated by the phenomenon of over-forecasting in transport, known as 'optimism bias'. But a brief reading of the early days of railway development in the U.S.A. and Europe would quickly reveal that optimism bias is actually an inherited trait, handed down over generations, which tends to emerge whenever the recessive gene of optimism becomes over-stimulated by the dominant gene of self-interest.[14]

The financial outturn for individual lines is an area where publicly available data is sometimes rather sparse, and it would take much more detailed study to draw other than the most general conclusions; but they are rather sobering. On the cost side, experience is that construction plus train-set costs, outside of China where the costs are significantly lower, typically range from USD 35-70 million/km, depending on the complexity of civil engineering works, the degree of urbanization along the route[15] and the total capacity of the rollingstock required (related to demand). Construction is generally cheaper where there is an existing rail corridor available, and when existing lines are used for the last few kilometers to bring trains into and out of an urban center. It is likely that there are economies from larger construction programs; certainly China has realized comparatively low unit rates on many components and processes due to the scale of the program, continuous working with few delays, and wage levels lower than in other countries where high-speed rail is being introduced.

Internationally (though not in China) many projects have taken very long periods to complete (over a decade is not unusual), creating a heavy capital and debt burden before any cash in-flows. Any delay in

[14] Whether professional or financial, the latter becoming prevalent when projects are supported by consultants and financial advisers working on a success-fee basis.

[15] Rolling stock and associated costs range from 10 to 25 percent of total costs, depending on the service frequency planned.

passenger ramp-up period or shortfall in ridership or yield can quickly create financial stress. Many lines internationally have run into trouble, and have had either to restructure debt or seek additional funding from government.

Operating and maintenance costs of high-speed rail are generally low by comparison with the capital costs, and speed delivers better equipment and train crew turn-round times. The Shinkansen lines of Japan East (which include the comparatively lightly-used Joetsu and Nagano lines) have a working ratio[16] of 40 percent and an operating ratio[17] of 55 percent. The TGV Sud Est line in France also had a working ratio of 40 percent for about a decade after it opened and an operating ratio (including interest) of just over 60 percent. Even the troubled THSR high-speed line had a working ratio of less than 50 percent within a year of opening.

However, repaying and servicing debt is another matter. Revenue from the initial Tokaido Shinkansen covered interest and depreciation by the third year. But other lines have been far less successful financially (unsurprising given the relative traffic volumes) and have been able to contribute very little, if anything, towards capital recovery. Shinkansen-related debt totalled JPY 5.7 trillion by 1987 when, partly because of it, Japanese National Railways were wound up. More recently, over 70 percent of the THSR line costs were associated with interest and depreciation and, despite a ridership of nearly 100,000 per day, the project has ended up having to be refinanced.

The evidence is that it is very difficult for a stand-alone high-speed railway to recover much of its capital costs from the passenger revenue stream alone, except in the very densest corridors. On some lines internationally, a high-speed line may create other positive net revenue streams that can be factored into the financial returns, such as in China where there is strong latent demand by freight customers for the capacity released by the transfer of many passengers to a new line. But for the most part, governments contemplating the benefits of a new high-speed railway, whether procured by public or private or combined public-private project structures, should also contemplate the near-certainty of copious and continuing budget support for the debt.

This is not to suggest that public financial support may not be justified, but rather to argue for a candid prior weighing of overall economic benefit against "likely" public financial support, rather than just "picking up the bill after the feast." This then begs the question of what are the wider economic benefits of high-speed rail services that should be assessed?

5. High-speed rail and economic development

An important question for governments and international development organizations such as the World Bank is how to view plans for high-speed railways in the context of economic development. Even if high-speed railways in a developing country can find a market of travelers willing and able to pay for the benefits of fast travel, this does not of itself imply that there is developmental interest in this sector of the transport industry. Indeed, considered in this light it might be said that very fast travel is a consumption good, and a luxury one at that; that it is generally affordable only by those in developing countries who

[16] The ratio of operating cost excluding depreciation to revenue.
[17] The ratio of operating cost including depreciation to revenue.

have already raised themselves above the masses of the poor who are rightly the focus of much of the world's developmental engagement. But is the narrow view justified? In our view it is not. It is certainly not a view that is applied when congested conventional roads are replaced by freeways or expressways, where the travel time and motoring cost savings of comparatively rich private car owners are often crucial to justifying development projects; just as the benefits to business travelers and rich tourists are part of the justification for airport development projects.

Indeed, transport infrastructure has traditionally been very much a focus of developmental interest. It is easy to see why this is so. Transport makes a multi-faceted contribution to economic and social development that includes passenger and freight operations, spans urban and rural areas, includes public and private transport, meets economic and social needs, and serves domestic and international demands.[18] Transport can facilitate or restrict regional integration through domestic and international trade. In an increasingly urbanizing world, transport can make cities work better or worse for their citizens, and make inter-city travel more or less convenient. Transport availability can create or stifle economic opportunity and growth in rural areas, and can provide rural populations with either good or poor access to social services. Through all these means transport can influence development potential and attainment, even though the precise mechanisms are not always well understood.

High-speed rail lines or, as in a China, a high-speed network, will therefore inevitably affect the overall performance of a country's transport system. In operational terms a high-speed line will naturally provide valuable travel time savings to its users but it may also free up capacity on existing lines for other transport users, and enable performance improvements on those lines due to lower congestion. It may also affect interconnected modes, and may alter both trip-making patterns and the relative usage of different modes of transport, creating resource savings if those other modes have higher unit costs of operation.

High-speed rail will also have various environmental and social consequences that may on balance be negative or positive. Certainly a high-speed passenger train will use more energy, and thereby generate more greenhouse gases, than a slower passenger train over the same route (see Figure 5, based on a Series 500 Shinkansen trainset).[19] But if the higher speed attracts passenger travel away from road and air transport, and/or (as in China) frees up rail capacity for freight, it may reduce the overall long-term carbon intensity of the transport system as a whole. Through mode transfer it will also reduce road

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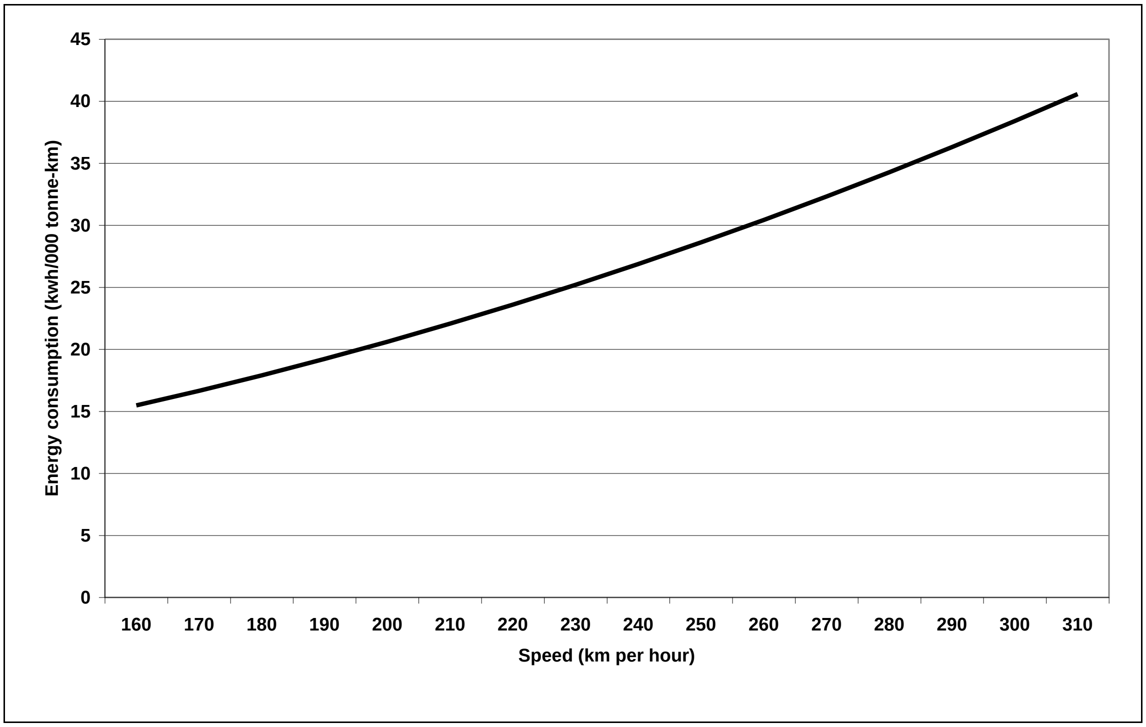
[18] World Bank (2007) *Safe, Clean and Affordable: Transport for Development*.

[19] On a straight level track, and when running at a constant speed, energy consumption is a function of the mass and average speed of train. At 200 km/h around 70 percent of the energy consumed is required to overcome wind resistance; this resistance increases as the square of the speed, and at 350 km/h around 90 percent of the energy consumed is required for this task. Figure 5 shows the relationship between energy consumption and speed for a Japanese Series 500 train, with a mass of 640 tons and 1,000 seats on a flat straight track at constant speed. When speed is increased from 250 km/h to 300 km/h, energy consumption is estimated to increase by 35 percent. In practice, consumption is also affected by factors such as distance between stations (as this influences the proportion of energy used for acceleration), gradient, driving style and the use of regenerative braking, and the use of energy for on-board services. As actual consumption for Shinkansen trains is around 40 kwh/000 ton-km at a maximum speed of 270 km/h, the consumption in Figure 5 needs to be increased by around 30 percent to reflect practical operating conditions.

accidents and other social costs of private vehicle travel. The overall balance of effects with regard to such externalities will depend very much on the specific project and market circumstances involved. Certainly, European Union transport policies explicitly based on the concept of environmental sustainability are very supportive, politically and through financial contributions, of the further development of a European high-speed railway network (though this has not persuaded all environmental groups, many of whom have recently demonstrated against the construction of new lines from Bordeaux to Madrid and Lyon to Turin).

Figure 5. Energy consumption as a function of speed



Fundamental changes in accessibility and mobility are also likely to influence regional economic development. These are the hardest effects to predict and quantify, and the World Bank is currently initiating baseline studies in China to try to assist in the long-term tracking of the impacts of a major new rail line.

So the overall developmental benefits of high-speed rail can be neither presupposed nor dismissed out of hand, though much professional opinion tends to be polarized into one of these positions. Like all large complex transport projects, promising high-speed rail transport routes require careful project appraisal to estimate costs and demand, and wide ranging cost-benefit analytical tools to assess economic, social and environmental impacts.

Nevertheless, policy-makers should start from what has been learned by experience elsewhere. High-speed rail projects tend to be strategic in nature, creating step-changes in performance rather than the incremental changes that are more amenable to the conventional tools of cost-benefit analysis. It is useful to look above the computations, and to take a strategic view of whether such plans really are “promising.”

Do they cohere with a credible long-term vision of a country's overall multi-modal transport network? Are they consistent with demography and settlement patterns and economic structure? Are they credible in terms of taxpayer and user affordability?

In this regard, the world's experience with high-speed railways, and now China's, provide useful indicators which can be examined ahead of detailed feasibility studies.

6. Preconditions for new high-speed rail systems

Intrigued by what they have seen happening in China and elsewhere, the world's transport policy- makers have become increasingly interested in high-speed rail. Increasing road congestion, the economic and human costs of road traffic accidents, congested airways and airports, and the threat of global warming have all contributed to a feeling that railways can and should play a much greater role in passenger transport. The same policy-makers know that conventional passenger rail services, with average commercial speeds typically in the range of, say, 80 to 140 km/h (often less) have been increasingly unable to hold market share. Many have concluded that the role of "slow" rail passenger services on major inter-city transport routes will become increasingly marginal. They have asked whether high-speed rail, which can out-perform both road and air transport measured against various quality criteria and over a significant range of typical intercity trip distances, may be the answer.

Based on international experience, what are the main preconditions or success factors for sensibly embarking on a high-speed rail project?

The most favorable starting point for a case for high-speed rail is an already congested trunk rail corridor (or if there is no rail link, a congested transport corridor) operating in markets with strong underlying growth. If the options for stretching the capacity of existing lines have been exhausted, then it is physically necessary to build new railway capacity anyway. The cost of building new railway lines is expensive (though normally cheaper than highways of the same capacity) but if the new line is required anyway, the more critical variable for a decision on high-speed rail is the incremental cost of providing that additional capacity with high-speed capability. The answer will of course depend on the terrain, the speeds involved and other factors, but international experience is that between 25 percent and 60 percent of the costs of high-speed track would in any case be required to build to conventional 160km/h speeds. Project appraisal should then focus on the incremental benefits of high-speed operation versus the incremental costs of attaining it.

If conversely there is substantial spare capacity on an existing corridor, it will be much harder to justify the capital costs of building a new high-speed line. Then the whole of the cost will need to be justified by service improvement alone rather than by the benefit streams released by both extra capacity and better service. Without those additional benefits, improving speeds on the existing lines up to, say, 200km/h may provide a higher economic return than a dedicated high-speed line.

The second promising indicator of potential economic viability is a corridor of exceptionally high and concentrated travel demand in the right distance band. A high-speed rail service can deliver competitive advantage over airlines for journeys of up to about three hours or 750 km, particularly between city pairs where airports are located far from city centers. For short journeys, say up to 100 kms, then private car transport is likely to be the main competitor, offering door-to-door travel not requiring a connecting trip to a high-speed train station. One suitable type of corridor is that which connects two large cities 250-500 km apart (Seoul-Busan, 420 km; Brussels-Paris, 275 km; Rome-Milan, 514 km; London-Paris, 495 km). But another promising situation is a longer corridor that has very large urban centers located, say, every 150-300 km (Tokyo-Osaka, 700 km; Beijing-Shanghai, 1,300 km; and Beijing-Guangzhou, 2,100 km). On these corridors high-speed rail has the ability to serve multiple, direct and overlapping, city pairs en-route.

For trip distances above 500 km, maximum speed above 300km/h may be needed to maintain competitive times relative to air transport. However, for shorter distances a maximum speed in the range of 200 to 250km/h may be adequate to win sufficient market share without the additional costs of attaining very high speeds.

Either way, the incremental cost of construction of high-speed rail systems can only be recovered in an environment of intensive use of the capacity created. A route that operates for 16 hours a day with an average of five pairs of trains per hour, each carrying 500 seats, will have a commercial capacity of about 80,000 passengers per day or some 30 million passengers per year. If effectively marketed it might expect to attain an average two-thirds load factor. In our view, whilst the day-to-day working expenses of a high-speed line can be covered at a relatively low traffic volume, a developing country must reasonably expect at least 20 million passengers per year with sufficient purchasing power, just to have the possibility of covering the working expenses and interest costs of providing that capacity with high-speed service, and probably double that number to have any possibility of recovering the capital cost.[20]

If extra capacity in a corridor is clearly required, but market potential is not large enough to justify dedicated passenger use, a new railway could be designed for freight as well as passenger operation. In such a case the maximum speed would need to be moderated.

Thirdly, and of particular significance in developing countries, even if the physical passenger flows look good, it is prudent to question if they have the purchasing power to deliver the revenue needed to avoid an unsustainable budgetary burden.

Ultimately, passengers have a choice of using alternative means of transportation, or sometimes of whether to travel at all. Choice will be impacted by the perceived value of time saved, convenience, comfort and so on, but beyond these variables is the basic fact of passenger affordability. In order to generate the required volume of passengers in developing countries it will be necessary not only to target the most affluent travelers but also to adopt a fare structure that is affordable for the middle income population and, if any spare capacity still exists, to offer discount tickets with restrictions on use and availability that can fill otherwise unused seats. In countries such as China and India that are experiencing rapid economic growth, the incomes and affordability of the target population of full-fare passengers is

[20] With longer trains and higher frequency the capacity of a dedicated passenger rail system could be theoretically as high as 150 million passengers per year, but it is noteworthy that the busiest high-speed railway line in the world, the Tokaido line in Japan, has 83 million passengers per year, about half that notional capacity.

increasing rapidly. In countries of both low incomes and low growth in incomes, affordability by a sufficient number of full-fare passengers will be a critical constraint.

International experience generally, and the initial experience on the newly opened Wuhan-Guangzhou dedicated high-speed passenger line in China, have confirmed that the market is price sensitive. In China the second class ticket is priced at US$72 (or about US$0.07 per km, as compared with US$0.24 in Japan). It appears to have been beyond the capacity or willingness to pay of many ordinary Chinese workers and farmers in China, but these are early days to assess exactly where the balance between use of conventional and high-speed trains will eventually settle.

Finally, the ultimate success of any high-speed rail system will also depend on its operational performance. It must be built with high interconnectivity to other modes, provide a high-quality ambience, and operate frequently in a safe and reliable fashion. Meeting these challenges is a complex task requiring seamless interaction of diverse technologies in the area of foundations, bridges, tunnels, track, power systems, communications, signaling, train sets, train management and safety, ticketing, and passenger movement.

Few developed or developing countries have all the skills required and most do not have the scale, capacity and long-term commitment applied in China to developing a strong domestic capability. For many countries the best or only credible way forward is therefore to concession the construction and operations to an external operator. But even then, many developing countries lack the capacity, resources and governance to successfully implement and administer concession structures for such large and demanding projects as a high-speed railway, particularly if it is likely to require the long-term commitment of a public budgetary contribution.

7. Conclusions

In summary then, high-speed rail is now a tried and tested technology that delivers real transport benefits and can dominate market share against road and airline transport over the medium distances that many inter-city travelers confront. However, the demographic and economic circumstances that could support the viability of high-speed rail are, in global terms, limited. The number of passenger transport corridors of the requisite length, that are already capacity constrained, and where there is sufficiently dense potential demand by people of adequate purchasing power, is limited; some may be in countries where the implementation capacity may be lacking.

The combination of supportive features that exist on the eastern plains of China such as the very high population density, rapidly growing disposable incomes, and the prevalence of many large cities in reasonable proximity to one another (creating not just one city-pair but a string of such pairs) are not found in most developing countries. Nor could all countries assemble the focused, collective capacity-building effort, and the economies of scale that result, that arise when a government can commit the country, politically and economically, to a decades-long program over a vast land area. Even in China, the sustainability of railway debt arising from the program as it proceeds will need to be closely monitored and payback periods will not be short, as they cannot be for such “lumpy” and long-lived assets. But a combination of those factors that create favorable conditions of both demand and supply, comes together in China in a way that is distinctly favorable to delivering a successful high-speed rail system.

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