High-Speed Rail Worldwide—Past and Future

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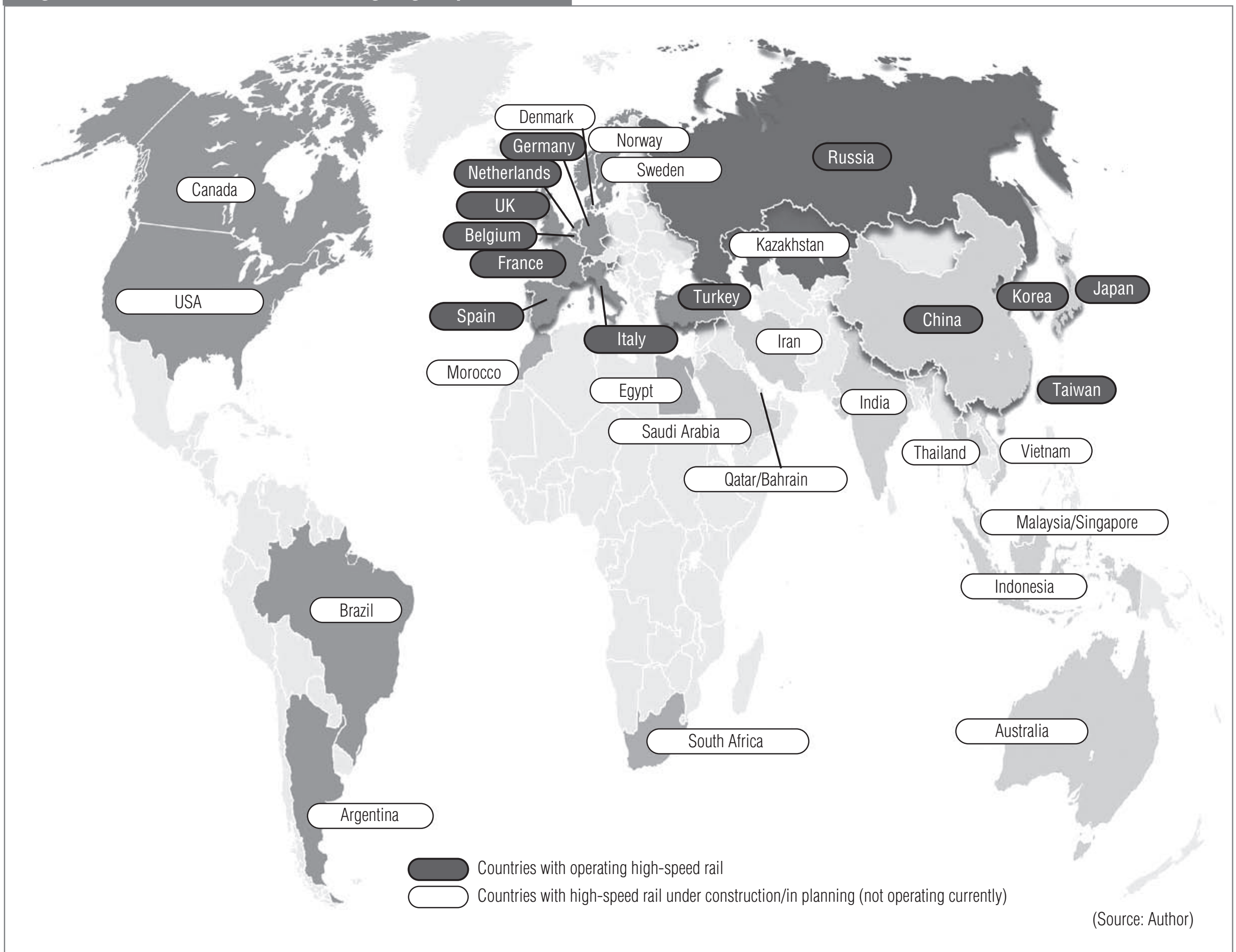
High-Speed Rail: A Start in Japan

Global spread

High-speed rail projects have been progressing worldwide in recent years. A high-speed rail network is being planned and built in Europe to link major cities and enhance the transport network within the European Union (EU). In Asia, with its high population density, high-speed railways are being constructed and plans formulated to stimulate further economic growth by linking large cities and improving transport infrastructure. China in particular is proceeding with a monumental construction plan spanning a total of about 20,000 km (including commercial operation at less than 250 km/h). In addition, even emerging economies are going forward with high-speed rail plans in the Middle East, South America, and Africa (Figure 1).

There are many factors behind this global spread of high-speed rail, including moves to switch from automobiles to railways due to increased awareness of the global environment, construction of major transport infrastructure for economic growth, and expectations for jobs creation and economic ripple effects.

Figure 1 Countries With or Planning High-Speed Rail



Pioneering Tokaido Shinkansen

Looking back at the history of high-speed rail, the Tokaido Shinkansen started operation as the world's first high-speed railway along the 515-km route between Tokyo and Shin-Osaka on 1 October 1964, just ahead of the Tokyo Olympics. It achieved revolutionary success and contributed greatly to Japan's high economic growth. At a time when railways were in decline due to the rise of personal automobiles, faster rail speeds between cities proved an effective stimulus in the resurgence of railways worldwide.

After studying the Tokaido Shinkansen technology in detail, France's TGV started operation in 1981 at what was then the world's fastest speed of 260 km/h. Today, Japan's shinkansen and France's TGV are the world's top high-speed rail systems, and the Tokaido Shinkansen can be said to be the pioneer in high-speed rail because it was the first to secure success.

JR Central's N700A on Tokaido Shinkansen (Author)

French TGV-POS and TGV-Duplex with top commercial operating speed of 320 km/h (world's fastest) (Author)

Table 1 Word's High-Speed Railways (in order opened, commercial operating speed ≥250 km/h)

No.	Country	Year opened	Length of specially built high-speed lines (km) (Note)	Maximum commercial operating speed (km/h)	Major trains
1	Japan	1964	2388	320	Shinkansen
2	France	1981	2005	320	TGV
3	Italy	1988	944	300	ETR and italo
4	Germany	1991	1228	300	ICE
5	Spain	1992	2225	300	AVE
6	Belgium	1997	209	300	Thalys
7	UK	2003	113	300	Eurostar
8	Korea	2004	412	300	KTX
9	Taiwan	2007	345	300	Series 700T
10	China	2008	9904	310	CRH
11	Turkey	2009	565	250	YHT
12	Netherlands	2009	85	300	Thalys
Total			20,423		

Note: At late December 2013 (Source: Author)

High-speed rail networks spanning 20,000 km

Subsequently, high-speed trains started running in the Western European nations of Italy (exemplified by ETR), Germany (ICE), Spain (AVE), Belgium (Thalys), the UK (Eurostar), and the Netherlands (Thalys). Following Europe, high-speed railways were also built in the East Asian countries of South Korea (KTX), Taiwan (Series 700T), and China (CRH). High-speed trains also started to operate in Turkey (YHT) and Russia (Sapsan) (Table 1).

There is now a total of 20,423 km of specially built high-speed lines (maximum commercial operating speed of 250 km/h or faster) worldwide (at late December 2013). Moreover, the maximum commercial operating speed of high-speed trains running on these lines is 300 to 320 km/h in most countries with high-speed railways.

Defining High-Speed Rail

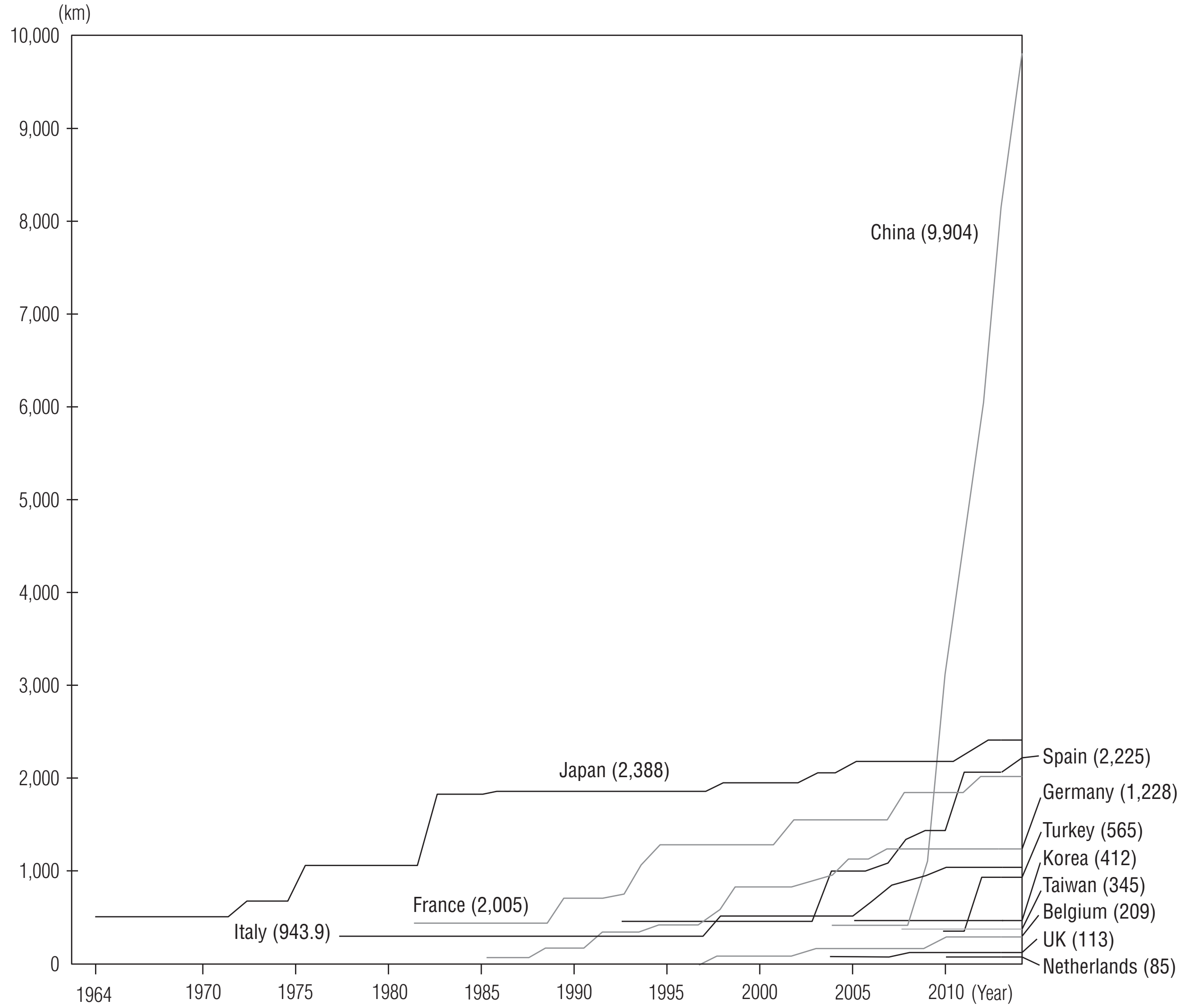
High-speed rail is often not defined clearly when discussed, so an explanation is provided here first. Article 2 of Japan's National Shinkansen Railway Development Act (1970) defines a 'shinkansen railway' as an 'artery railway that is capable of operating at the speed of 200 km/h or more in its predominating section'. This might be used as the definition of high-speed rail, but most conventional lines in Europe are standard gauge (1435 mm) with fewer curved and graded sections than in Japan, so the UK, France and Germany have many lines capable of operations at around 200 km/h even without constructing specially built lines. Thus, defining high-speed rail as having speeds of 200 km/h or more would make organizing statistical data on the total length of high-speed rail very difficult when comparing individual countries.

The International Union of Railways (UIC) tabulates specially built high-speed lines equipped for operation at 250 km/h or faster as high-speed rail. With advances in technological development of higher speeds, high-speed operation in the 300 km/h or faster range is becoming the norm globally. Therefore, it is not practical to define high-speed rail as having speeds of 200 km/h or more.

Defining high-speed rail as having a maximum commercial operating speed of 250 km/h or more eliminates high-speed conventional lines of around 200 km/h and limits the definition to dedicated specially built high-speed lines on which high-speed trains run. This definition is used in this article.

It is worth noting that a conventional line between Moscow and St Petersburg in Russia was upgraded to run *Sapsan* (Peregrine Falcon) high-speed trains with a maximum commercial operating speed of 250 km/h. While this is a conventional line, not a specially built high-speed line, here it is treated as a high-speed rail line.

Figure 2 History of High-Speed Construction of Specially Built High-Speed Lines



Note: Numbers in parenthesis are length of specially built high-speed lines at late December 2013

(Source: Author)

High-Speed Rail Technical Development Trends and Data Comparisons

History of construction of specially built high-speed lines

Japan held the title of having the greatest length of high-speed rail lines in the world for a long time after the opening of the Tokaido Shinkansen in 1964. However, China took the lead in 2009 as it rapidly built a high-speed rail network connecting major cities from the beginning of the 21st Century. At late December 2013, China had 9904 km of specially built high-speed lines (48% of global total of 20,423 km), making it a high-speed rail giant in a short time span (Figure 2).

In Europe, France, Germany, Spain, and Italy are gradually expanding the length of their high-speed lines in accordance with the high-speed rail plan for Europe as a whole. Recent growth by current third-place Spain (2225 km, 11% of global total) has been dramatic, closing in on second-place Japan (2388 km, 11%).

Construction and planning of high-speed rail in emerging economies is progressing, but only Saudi Arabia and India come even close to developed high-speed rail countries in terms of track length. Their future developments will be watched closely.

Maximum Commercial Operating Speed

The current maximum commercial operating speed is 320 km/h in France (TGV), Germany (ICE3), and Japan (*Hayabusa* and *Komachi*). The Chinese high-speed railway that opened between Beijing and Tianjin (115 km) in August 2008 in conjunction with the Beijing Olympics initially started at the world's fastest commercial operating speed of 350 km/h, and the high-speed railway between Wuhan and

Guangzhou (968 km) that opened in December 2009 also started at 350 km/h. However, the 23 July 2011 collision and derailment at Wenzhou, Zhejiang Province, caused speeds to be lowered to about 310 km/h.

As an aside, the speed record for iron wheel on rail high-speed trains is 574.8 km/h set by France's TGV on 3 April 2007 before the opening of the LGV Est Line. The italo high-speed train developed by Alstom based on the test train that set this world speed record was dubbed the ETR 575.

Maximum average speeds between stops

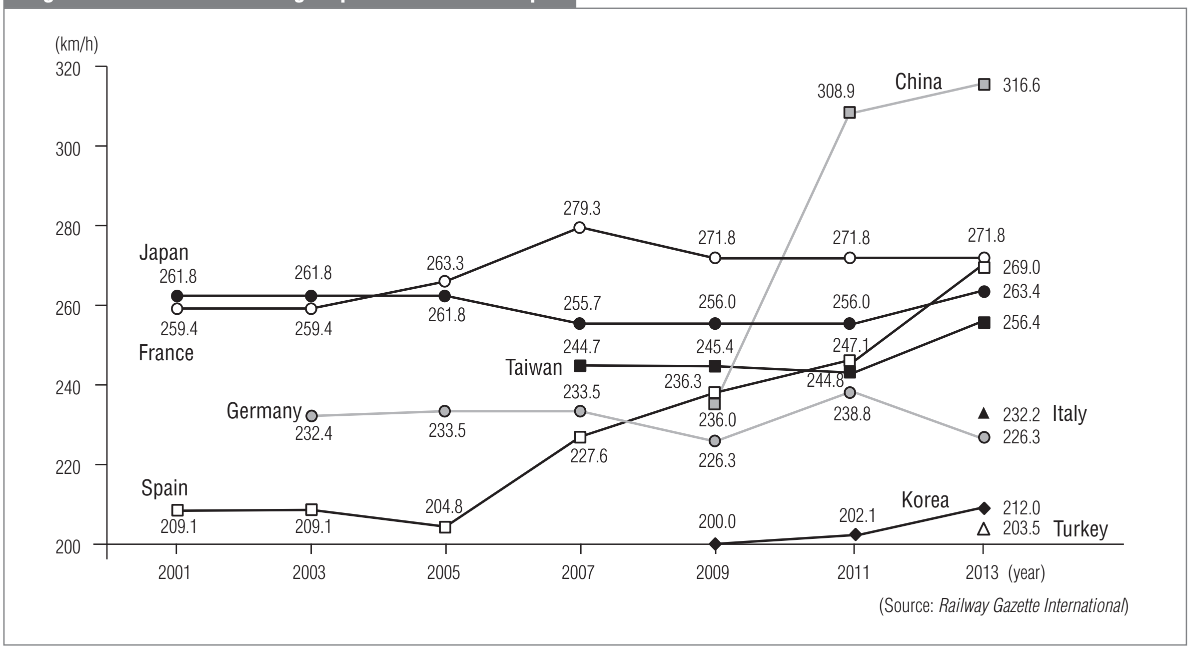
Every 2 years, *Railway Gazette International* announces the ranking of average speeds between stops for high-speed

China's CRH3 operating between Wuhan and Guangzhounan (Author)

italo with distributed traction system operated by Italy's NTV (Author) railways in commercial operation in individual countries. Figure 3 shows a table summarizing data from 2001 to now. These figures are calculated from Thomas Cook's *European Rail Timetable* and *Overseas Rail Timetable*.

In the latest ranking from 2013, China's prominence really stands out with a maximum average speed of 316.6 km/h on the Shaoguan–Leiyang Xi section of the specially built high-speed line between Wuhan and Guangzhou. This record is followed by France's LGV Est Line between Larraine TGV and Champagne-Ardenne TGV at 271.8 km/h, Spain's Madrid–Barcelona high-speed line between Guadalajara-Yebes and Calatayud at 269.0 km/h, Japan's Tohoku Shinkansen between Omiya and Sendai at 263.4 km/h, Taiwan between Zuoying and Tahichung at 256.4 km/h, Italy between Milano Rogoredo and Bologna Centrale at 232.2 km/h, Germany's Köln–Frankfurt high-speed line between Frankfurt Flughafen and Siegburg/Bonn at 226.3 km, Korea's Gyeongbu High Speed Railway between Gwangmyeong and Daejeon at 212.0 km/h, and Turkey's line between Eskisehir and Polatli at 203.5 km/h.

Figure 3 Maximum Average Speed Between Stops



Spain's AVE S102 (Author)

Russia's 1520-mm gauge *Sapsan* (Author)

Eurostar international high-speed train (Author)

Gauge and interoperability

Most countries with high-speed railways have adopted standard gauge (1435 mm) for specially built high-speed lines. In other words, while Japan and Taiwan use narrow gauge (1067 mm) for conventional lines and Spain uses broad gauge (1688 mm), the gauge of specially built high-speed lines is 1435 mm. However, the conventional line (1520 mm) between Moscow and St Petersburg in Russia was upgraded to operate *Sapsan* high-speed trains at a maximum commercial speed of 250 km/h.

The gauge of conventional lines in Europe, South Korea, and China is also 1435 mm, so high-speed trains running on specially built high-speed lines can run through-services directly onto conventional lines. Consequently, in those countries, the ripple effect of speed increases is much greater than in Japan where conventional lines (1067 mm) and shinkansen lines are different gauges.

In Europe, international high-speed trains such as


Thalys international high-speed train (Author)

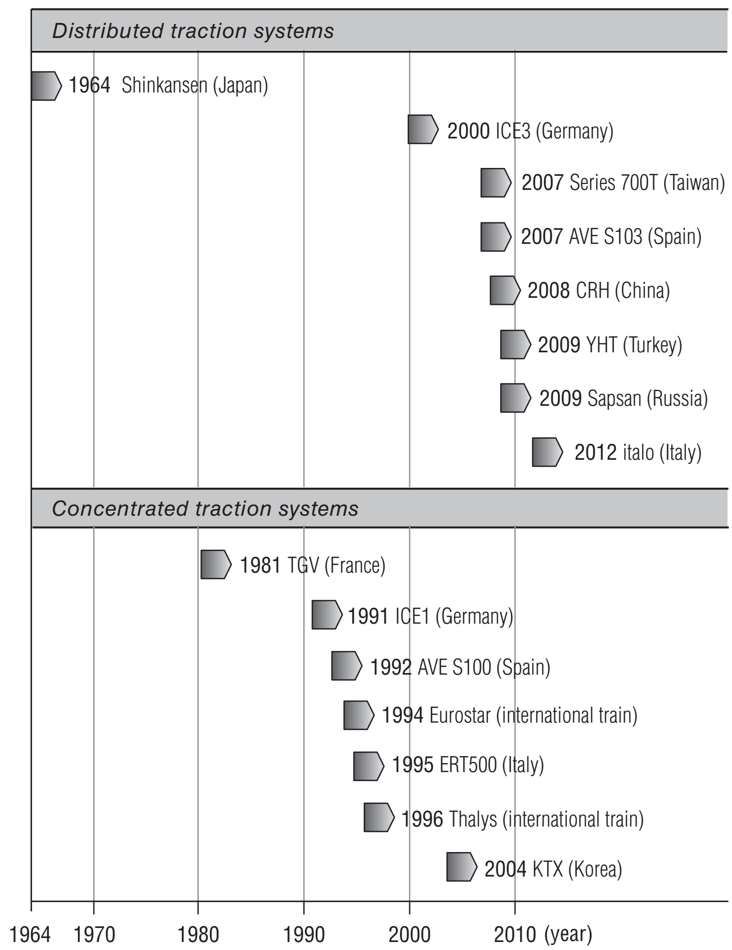
Eurostar and Thalys were developed to run on different electrical and signalling systems to enable interoperability between EU countries. The TGV and ICE also operate across borders.

Distributed Traction and Concentrated Traction Systems

There are two types of high-speed trains: the EMU type (distributed traction system) such as Japan's shinkansen, where motors are installed in passenger cars, and the type where locomotives are placed at each end (concentrated traction system) such as France's TGV. Japan has always used the distributed traction system since the original Tokaido Shinkansen. Since the inception of the French TGV in 1981, the concentrated traction system has been the main type used in Europe such as on Germany's ICE1, Spain's AVE S100, the international high-speed Eurostar, Italy's ETR500, and Thalys (Figure 4).

The distributed traction system has many advantages in terms of energy efficiency and efficient transport. Major examples are light axle weight, high acceleration and deceleration, more cabin space as there are no locomotives, and ability to utilize the energy of regenerative braking

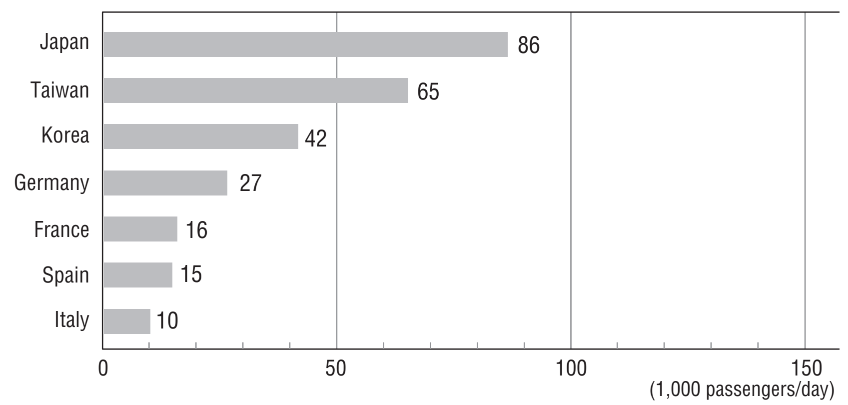
Figure 4 Distributed Traction and Concentrated Traction Systems



(Source: Author)

German ICE3 with distributed traction system (Author)

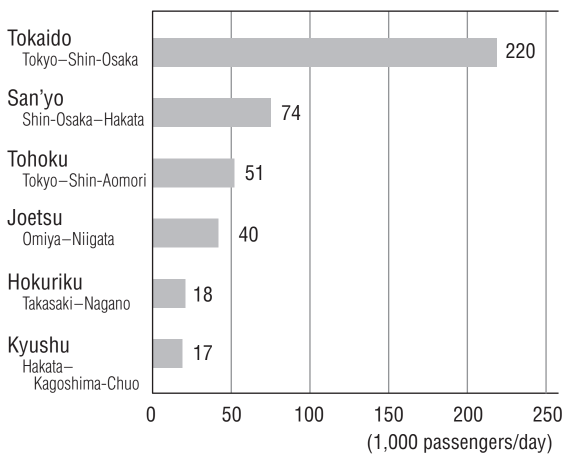
Figure 5 High-Speed Rail Transport Density of Major Countries Worldwide (2011)



Note: Transport density in the above figure is annual passenger-km ÷ 365 days ÷ length of line operating in excess of 160 km/h

(Source: UIC *International Railway Statistics 2011*)

Figure 6 Shinkansen Transport Density (fiscal 2011)



(Source: *Railways in Figures 2013* Edited by Railway Bureau of the Ministry of Land, Infrastructure, Transport and Tourism)

efficiently. Moreover, compact and light AC motors have been used instead of conventional DC motors since the Series 300 shinkansen, reducing motor maintenance. These advantages prompted European and Asian railways to adopt the distributed traction system as the main type, starting with the German ICE3 that debuted in 2000.

Transport Density

Transport volume differs with factors such as population, economic strength, and industrial structure of cities along high-speed railways. Transport density is an index often used to compare transport volume of different lines. Transport density (passengers per day) calculated as annual passenger-km ÷ 365 days ÷ kilometers of commercial lines expresses the average transport volume (number of passengers) per km per day, and it is unaffected by the line length.

Figure 5 shows the 2011 transport density of high-speed railways in major countries based on UIC data. This figure

Korea's KTX and KTX-Sancheon based on French technology (Author)

shows Asian high-speed railways running in regions of dense population (Japan, Taiwan, South Korea) rank at the top. It is necessary to be careful when looking at Figure 5 to note that UIC data is assumed to include the transport volume of high-speed trains where those trains travel on conventional lines (maximum commercial speed in excess of 160 km/h), so the transport density on just specially built high-speed lines in South Korea and Europe may be greater than shown. Transport density on European specially built high-speed lines is about 20,000 to 30,000 people per day, and to give railways a competitive advantage over other transport modes, it is necessary to exempt railway companies from bearing infrastructure costs. So policies to separate infrastructure and operations are inevitably adopted. Unfortunately, the UIC data does not include China's high-speed railways, so comparisons cannot be made, but it would be interesting to know how many people use high-speed rail in China.

Comparing the transport densities of Japan's shinkansen, Figure 6 shows the Tokaido Shinkansen is overwhelmingly large at 220,000 passengers per day (fiscal 2011 here and hereafter), giving it the greatest high-speed rail transport density in the world. That is followed by the San'yo Shinkansen at 74,000 passengers per day, the Tohoku Shinkansen at 51,000, and the Joetsu Shinkansen at 40,000. The Hokuriku (Nagano) Shinkansen and Kyushu Shinkansen, built as a part of projected shinkansen lines, based on the Nationwide Shinkansen Railway Development Act, have transport densities of 18,000 and 17,000 passengers per day, respectively.

The transport densities of these high-speed railways differ greatly by line, so the number of cars per train set, number of train runs, and wayside equipment are designed based on transport demand. Moreover, since transport volume affects profitability, business schemes and funding for constructing high-speed railways differ by line.

Technology transfer from pioneers to other countries

Currently, the only countries with high-speed railways that developed their own systems from the start are Japan, France, Germany, and Italy. All other countries introduced systems from these high-speed rail pioneers to build their high-speed railways. Roughly, Spain based its high-speed rail on technology from France and Germany; Belgium, the UK, the Netherlands, and South Korea on that from France; Taiwan on that from Japan; China on that from Japan, France, and Germany; and Russia on that from Germany.

Taiwan's Series 700T based on Japan's Series 700 (Author)

In recent years, Spain, South Korea, and China too have expressed the intention to participate in overseas high-speed rail projects through transfer of high-speed rail technologies. For example, the Spanish rolling stock manufacturer CAF is delivering YHT (Yüksek Hizli Tren, meaning high-speed train in Turkish) high-speed rolling stock for Turkey's high-speed railway.

Competitive distance range

Conventionally, the range at which high-speed rail has the advantage over air and automobiles has been said to be within a travel time of 3 hours and distance of 300 to 500 km (this range may differ depending on set fares and operation frequency). However, it has expanded recently to about 4 hours or 300 to 800 km due to increased time for security checks at airports relating to the threat of terrorism, traffic congestion on the way to the airport in some cities, increased amenities on high-speed trains, and speed increases to over 300 km/h.

For reference purposes, the Eurostar connecting London and Paris (492 km) carries more than 80% of the passengers travelling between those cities. In Spain, the completion of a specially built high-speed line between Madrid and Barcelona (621 km) in February 2008 caused a sharp increase in the share for railways from 12% to 41%.

Construction and Planning in Countries without High-Speed Rail

As stated at the start of this article, high-speed railways are being constructed, planned or investigated, and bidded around the world for reasons such as to create economic growth corridors and improve environmental issues and energy efficiency. While the level of maturity of these new projects ranges from the idea stage to the implementation stage, high-speed rail construction and planning is ongoing worldwide, including Asia (Vietnam, Thailand, Malaysia, Singapore, Indonesia, India, Kazakhstan), the Middle East (Saudi Arabia, Qatar, Iran), Europe (Russia, Sweden, Norway, Denmark), Africa (Morocco, Egypt, South Africa), the Americas (Canada, USA, Brazil, Argentina), and Oceania (Australia).

In countries that do not have high-speed rail yet, construction has already started in Saudi Arabia on the Haramain High-Speed Rail linking Mecca and Medina for transporting pilgrims, and in Morocco. Construction in Morocco is based on introducing the TGV system, and all-bi-level TGV Euroduplex cars will be operated when it opens in 2015. Spain's Talgo and 'big three' member Bombardier received orders for Saudi Arabia's high-speed rail system and construction is currently underway.

Future Outlook

Era of top operating speeds above 350 km/h

The current top commercial operating speed is 320 km/h, but a speed of 350 km/h has been achieved in China (albeit temporarily). In Italy, the ETR1000 high-speed train is scheduled to be introduced in 2015 with a top commercial operating speed of 360 km/h. In other words, the top commercial operating speed of high-speed rail will soon exceed 350 km/h. Since the distance at which high-speed rail has an advantage over air travel is determined by travel time, increasing the scheduled speed to about 300 km/h gives high-speed rail the advantage at distances up to about 1000 km. However, further speed increases are not necessary to maintain the advantage when there is no competition with other forms of high-speed transport, especially air travel.

Level of maturity and feasibility of high-speed rail projects

Planning and construction of high-speed railways is spreading from the traditional markets of Western Europe and East Asia to other countries as well. Making high-speed rail a reality requires securing profitability of projected lines, national economic power, political will, and international events such as an Olympics as a completion target.

Looking at the 10 high-speed rail project corridors currently planned in the USA, nearly identical routes were considered and surveyed as far back as the 1980s. People who thought high-speed rail could be achieved in Taiwan were a minority when the implementation plan was formulated more than 20 years ago, but it opened in 2007. Moreover, there was excitement around 1990 when it was suggested that Australia would soon be starting construction on a high-speed rail project, but that project is still in the planning stage. In other words, while many high-speed rail projects are being planned currently, it is important to realize that some will be achieved while others will not.

Challenges in achieving high-speed rail

It goes without saying that railways are an industry closely related to the characteristics of the countries and regions where they are deployed, reflecting the natural and social environment, so a high-speed rail system that fits the country or region must be adopted. Transport density has already been mentioned above, but the expected transport density of high-speed railways being planned worldwide today is only equivalent to that of projected shinkansen lines in Japan. Taking these factors into account, high-speed rail must be planned considering the transport situation in the countries where it is to be introduced. Freight transport was also considered for the Tokaido Shinkansen when it was originally planned, so high-speed rail projects where profitability is achieved by including freight transport are a possibility.

Many recent high-speed railways have been planned as public-private partnerships (PPP) projects. Under such schemes, private-sector financing and technology are supplemented by public funds and governmental cooperation to develop high-speed railways. With PPP, many challenges have to be considered at planning, including how to bear demand risk, methods for procuring funds from the public and private sides, establishment of special-purpose companies (SPC), construction and rolling stock procurement, operation and maintenance.

Moreover, projects in developing countries often involve greater risk than in countries with advanced high-speed railways. For example, an Iranian high-speed railway modelled on the Japanese shinkansen was being planned to link the capital of Tehran with the holy city of Mashhad during the reign of Shah Pahlavi, but that vanished with the 1979 Iranian revolution. In Korea, the Gyeongbu High Speed Railway linking the capital Seoul with Busan was in danger of not coming to fruition due to the 1997 currency crisis, but then-president Kim Dae-jung made the decision to split construction into two phases, saving the project from failure.

In any case, there are many challenges that must be considered and dealt with from planning to achievement of high-speed rail projects. The era of constructing and opening specially built high-speed lines where transport demand is high is already coming to an end, and future high-speed railways must come up with business schemes and methods for procuring funds where there is lower transport demand. Strong leadership by politicians in those countries as well as financial soundness are imperative for bringing such projects to fruition. ■

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