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Development and Impact of the Modern High-speed Train: A Review

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ABSTRACT *The inauguration of the Shinkansen high-speed train service between Tokyo and Osaka, Japan, at 210 kph maximum operating speed some 40 years ago marked the comeback of the train as an important passenger mode of transport. Since then high-speed train (HST) services have been introduced in many countries and are planned in many more, and the train has once more become the dominant mode of transport on many routes. This review summarizes the different elements of HST operation with the aim of characterizing HST operation and putting in context its impact in terms of what it is best designed for and what it can deliver. The review concludes that the HST is best designed to substitute conventional railway services on routes where much higher capacity is required and to reduce travel time, further improving the railway service, also against other modes, therefore leading to mode substitution. However, the high investment in HST infrastructure could not be justified based on its economic development benefits since these are not certain. Finally, the following definition for HST services is suggested: high capacity and frequency railway services achieving an average speed of over 200 kph.*

Introduction

> Transport technologies seldom make a comeback, save in nostalgia trips for well-heeled tourists. … But there is a spectacular exception: railways, written off thirty years ago as a Victorian anachronism destined to atrophy before the steady growth of motorway traffic, have suddenly become one of the basic technologies of the twenty-first century.
>
> The reason of course is the high-speed train (Banister and Hall, 1993, p. 157)

On 1 October 1964, the first high-speed train (HST) passenger service was launched on the Tokaido line between Tokyo and Osaka with trains running at

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speeds of 210 kph. This date marks the beginning of the modern HST era. Since then, the HST network has expanded, first in Japan, and later in other countries, and speeds have increased. Today, about 40 years later, the HST is in many respects a distinct mode of transport.

There is no single definition for high speed in the context of railway services, although the reference is always to passenger services and not to freight. High speed can relate to the infrastructure capability to support high speed (this might explain the term 'high-speed rail' (HSR), in addition to the fact that train and rail (or railway) are often used synonymously), the rolling stock capability to achieve high speed and/or the actual operation speed achieved. The European Union (EU) definition, given in Directive 96/48 (European Commission, 1996a), is 250 kph for dedicated new lines and 200 kph for upgraded lines in respect of the infrastructure capabilities. The same applies to the rolling stock (on specially built and upgraded lines, respectively). With some HSTs operating at speeds of 350 kph, 200 kph might not seem high speed anymore. However, HST operation is not all about (maximum) speed. Other elements are as or even more important in the overall consideration of HST as a mode of transport and in the developments of HST lines.

This review examines the different elements of HST operation and puts HST operation in context in terms of what the HST can deliver and what can be expected from the introduction of HST services. It is a synthesis of the existing literature and current state of the art. It begins by describing the main technological developments in railway technology required to operate HST services (the second section) followed by definition of four models of HST (third section). Next, the development of the HST network across the world is described (fourth section). The focus then shifts to analysing the impacts of HST services, first the transport impact (e.g. effect on travel time and modal share; the fifth section) is considered, followed by the spatial and socio-economic impacts (sixth section) and the environmental impact (seventh section). The cost of HST lines is examined (eighth section) before conclusions are drawn (ninth section).

Technological Evolution of the Present HST

Traditionally, a speed of 200 kph was considered as the threshold for 'high speed' (Ellwanger and Wilckens, 1994), which was achieved in Germany in tests as early as 1903. In 1955, the French set a new speed record of 331 kph and they also hold the current speed record for a 'steel wheel on steel rail' train of 515 kph achieved in 1990 by a French TGV HST (Whitelegg and Holzapfel, 1993). However, the commercial speed that can be achieved is of greater importance. The maximum operating speed on the Tokaido line now stands at 270 kph (Central Japan Railway Company, 2003), while on the TGV Atlantique line trains operate at a maximum speed of 300 kph. The standard for new lines is even higher, at 350 kph, which is the official maximum operating speed of new HST lines such as the Madrid–Barcelona line (International Union of Railways, 2003). Higher operating speeds seem commercially unfeasible at present due to noise problems, high operating costs and other technical problems.

The modern HST uses the same basic technology of a steel wheel on a steel rail as the first trains did at the beginning of the 19th century. Yet, many incremental engineering and technological developments were required in all aspects of train operation to allow trains to run commercially at speeds higher than 200 kph. Although much higher speeds were reached in tests by simply using more power to propel conventional trains, these speeds were 'deemed infeasible for commercial application because the fast-moving vehicles damaged the tracks severely' (Raoul, 1997, p. 100). In addition, the increase in the centrifugal forces as speed increases when trains run through curved sections led to discomfort to passengers and, furthermore, it is not enough that the train is capable of running at high speed, but the track must supports trains running at high speeds.

The main technical challenges in the development of commercial HSTs were to develop a train and track that could maintain stability and the comfort of passengers (while the train is running at high speed), maintain the ability to stop safely, avoid a sharp increase in (train) operating costs and (track) maintenance costs, and avoid an increase in noise and vibration to areas adjacent to the line. The solution included, in most cases, building tracks that avoid tight curves; increasing the distance between axles in the bogies to help maintain stability and placing the bogies between carriages (and not at the ends of each carriage) to reduce weight by halving the number of bogies required to carry the carriages; improving stability by preventing the cars from pivoting away from one another on curves; designing aerodynamic trains to reduce drag and shaping the train in a way that reduces the noise and vibration it induces; and using lighter and stronger materials (Raoul, 1997). In addition, the high speed required improvements to the signalling systems, the introduction of automatic braking/decelerating systems to improve safety, and changes in the operation of trains, e.g. the need to replace roadside signals with signals inside the driver's cab since at high speeds the trains passed the roadside signals too fast for the driver to see them.

Main Models of HST

The different needs and special characteristics of the different countries pursuing the development of HST operation led to the evolution of different models of HSTs. The Japanese Shinkansen, which was the first modern HST in operation, can be considered as the base model for HST. Subsequently, three other models have evolved.

The Shinkansen

The main features of the Shinkansen ('new trunk line', and the name given to the Japanese HSTs) evolved from Japan's unique characteristics which include large metropolitan centres located a few hundred kilometres apart from each other with a high demand for travel between them. For example, the Tokaido line connects Tokyo, Osaka and Nagoya, Japan's biggest cities (approximately 30, 16 and 8.5 million inhabitants, respectively), which are a few hundred kilometres apart from each other (Tokyo–Osaka 560 km with Nagoya located on the route 342 km from Tokyo) and generate high demand for travel between them (132 million passengers on the Tokaido Shinkansen in 2002; Central Japan Railway Company, 2003). A unique feature of the Shinkansen is the new dedicated line which in the case of Japan was required since the conventional railway network is narrow gauge and could not support HSTs. This isolates the Shinkansen services from the rest of the railway system in Japan. The geographic features of Japan together with the requirement to avoid tight curves and steep gradients (to allow for high speeds) resulted in many tunnels and bridges along the route, which is typical of the Shinkansen lines. A total of 30% of the Japanese Shinkansen lines run through tunnels (Okada, 1994) leading to very high construction costs. Furthermore, construction of new lines into the city centres further exacerbates construction costs due to engineering complexity and the high land values in city centres.

The TGV

The French TGV (Train à Grande Vitesse), which began operation in 1981, resembles the Shinkansen in purpose but differs in design philosophy. The differences are attributable to some extent to overcoming the disadvantages of the Shinkansen and to the different physical characteristics of France and Japan (Sone, 1994). The most significant difference between the TGV and the Shinkansen is probably the ability of the former to operate on conventional tracks as well, which allows the TGV to use the conventional lines as it enters and leaves the city centre, leading to significant cost savings. It also means that the HST can serve regions with no HST infrastructure and specifically serve parts of the network where at present the demand is not high enough to justify the construction of a dedicated line (Bouley, 1986).

The Spanish HST, the AVE (Alta Velocidad Espanola, or Spanish High Speed), is a mix of the TGV and Shinkansen models. It uses a TGV-type rolling stocks, but like the Shinkansen it runs on a dedicated line throughout, because the Spanish conventional network is wider then the standard International Union of Railways (UIC) gauge used across most of Europe. This was favoured to allow the AVE to connect with the emerging European, and mainly French, HST network (Gómez-Mendoza, 1993).

Germany's HST, the ICE (Inter-City Express), follows the TGV model of HST, mainly in the compatibility feature. It deviates from the TGV and the Shinkansen models by adopting a mixed-use line, meaning the line is used for both passenger and freight transport (Bouley, 1986). This feature turned out to be a disadvantage since it led to high construction costs (to support the higher load of freight trains) and low utilization of the lines (since freight trains operate at much lower speeds).

The Tilting HST

The Japanese, French, Spanish and German HST trains all use a newly built track on the sections where high speed is achieved, which translates into high construction costs. Yet, on many routes demand is not high enough to justify the cost of constructing new tracks that allow high-speed operation. This problem was solved by the tilting train model of HST, but at the price of lower speeds. To allow higher speeds on conventional lines with tight curves, the train tilts as it passes through curves. By simply tilting the train in tight radius curves (although by a sophisticated computerized mechanism), the discomfort passengers feel from the centrifugal force as the train goes at high speed through curves is solved. 'The bogies remain firmly attached to the rails while the body of the carriage tilts, and so compensates for centrifugal force' (Giuntini, 1993, p. 61). This principle is adopted by many countries as a cheaper alternative to the TGV and Shinkansen models of HST. The Swedish X-2000 and the Italian Pendolino (ETR-450) are examples of HSTs running on conventional rail using the tilting mechanism, thus avoiding the price of expensive new tracks, but reaching maximum speed of only

210 kph (X-200) or 250 kph (ETR-450). Today, a tilting mechanism is also used on TGV trains, like the TGV Pendulaire, which can reach a maximum speed of 300 kph (International Union of Railways, 2003) and all the new Shinkansen models will adopt a tilting mechanism (*Japan Railway and Transport Review*, 2005).

The MAGLEV HST

If the tilting train model of HST is considered a downgrade from the Shinkansen and TGV models, mainly in terms of speed, the MAGLEV model of HST is an upgrade. Magnetic levitation (MAGLEV) technology was first tested in the 1970s, but it has never been in commercial operation on long-distance routes. The technology relies on electromagnetic forces to cause the vehicle to hover above the track and move forward at theoretically unlimited speeds. In practice, the aim is for an operation speed of 500 kph (Taniguchi, 1993). In 2003, a MAGLEV test train achieved a world record speed of 581 kph (Takagi, 2005). The special infrastructure required for MAGLEV trains means high construction costs and no compatibility with the railway network. The MAGLEV is mostly associated with countries like Japan and Germany where MAGLEV test lines are in operation. In Japan, the test line will eventually be part of the Chuo Shinkansen between Tokyo and Osaka connecting the cities in about 1 hour compared with the present 2.5 hours. In China, a short MAGLEV line was opened in December 2003 connecting Shanghai Airport and the city's Pudong financial district with trains running at maximum speed of 430 kph (*International Railway Journal*, 2004). However, plans to adopt MAGLEV technology for the planned Beijing–Shanghai route were abandoned in favour of a conventional steel wheel-on-steel rail HST (*People's Daily*, 2004). The future of the MAGLEV, it seems, depends on its success in Japan, in the same way the development of the HST depended largely on the success of the first Shinkansen line.

The main differences between the four models of HST described above in terms of maximum operating speed, compatibility with the conventional network and construction costs are summarized in Figure 1. In general, the reference in the present paper is to the Shinkansen and TGV models of HST.

Development of the HST Network

Despite the success of the Tokaido line in Japan, the spread of the HST around the world was relatively slow. It took 17 years after the opening of the Tokaido line for the first HST to be introduced outside Japan (in France) and another 7 years for the second European HST (and the world's third) to begin service in Italy. At present, the HST covers much of Japan and Europe and is being introduced in the Far East. The USA in this respect is lagging behind (see below).

In Japan, the success of the Tokaido line prompted the development of a Japanese HST network that was developed over time (Matsuda, 1993). This network (Figure 2) consists today of 2175 km of HST line in operation, with a further 215 km under construction and 349 km at the planning stage (International Union of Railways, 2003). The HST line between Paris and Lyon, which opened in 1981, was France's first HST. This line also proved to be a success story, and in turn the driving force for developing the French HST (Polino, 1993). At present, the French HST network consists of 1541 km of HST lines in operation, 320 km under construction and another 937 km at the planning stage (International Union

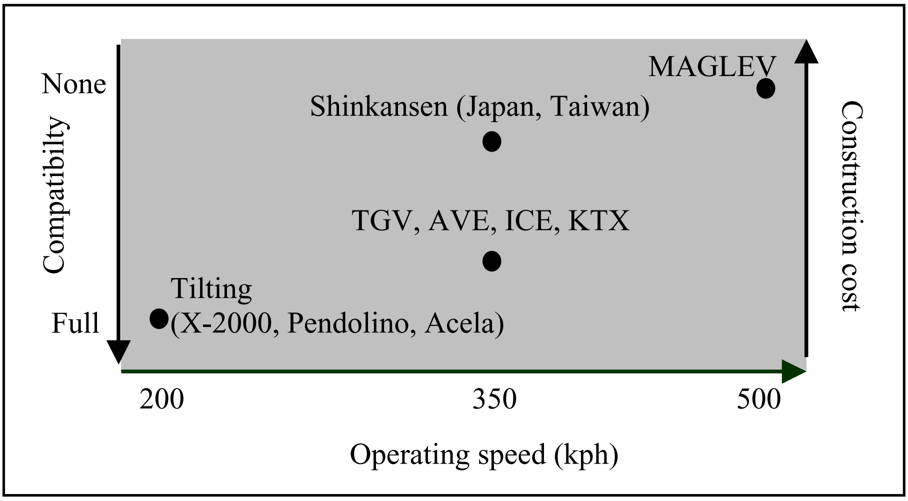

Figure 1. Operating speed, construction cost and compatibility (with the conventional network) characteristics of the four high-speed train models

of Railways, 2003). Despite the successful introduction of the HST in France, its spread across Europe was relatively slow. In 1988, the Italians introduced the Pendolino tilting train (ETR-450 model) on the Rome–Milan route; and in 2000 Sweden introduced its first HST, the X-2000, also a tilting-train model of HST. Next, in 1991, it was Germany's turn to introduce the ICE between Hannover and Würzburg; and a year later Spain introduced its first HST service between Seville and Madrid. The UK joined the list of countries with HST lines in 2003 when the first phase of the link from London to the Channel Tunnel (the Channel Tunnel Rail Link, or CTRL) was opened. This line is scheduled for completion in 2007.

Figure 2. Japan's high-speed train network

When the above European countries were independently pursuing their HST plans, and France was pursuing the expansion of its HST network to neighbouring countries, the EU emerged and with it the idea of the Trans-European Networks (European Commission, 2001). The international dimension of the European HST network (Figure 3) increases the scope for HST services since many countries, e.g. Belgium and the Netherlands, do not have domestic routes that can justify HST services.

Besides Japan and Europe, HST development takes place mainly in the Far East. South Korea became the eighth country with trains operating at 300 kph in April 2004 when its HST, the KTX (Korea Train eXpress), which is a TGV model of HST, began operation. In 2005, Taiwan completed its 345-km HST line between Taipei and Kaohsiung, the first country to adopt Shinkansen technology outside Japan. China, as noted above, is also underway to join the countries operating HSTs with a planned line between Beijing and Shanghai (Takagi, 2005).

In the USA only one HST line is in operation: the Acela Express tilting train running on the North East Corridor line between Boston and Washington, DC. At present, ten corridors across the USA have been designated for HST operation, but the start of construction still seems far way. The Californian HST, connecting the San Francisco Bay area with Los Angeles and San Diego, is at the most advanced planning stages (Federal Railroad Administration, 2005). Current debate in the USA on the future of Amtrak, the US passenger rail company, and the level of subsidies it should receive casts more doubts on the prospects for HST. With no funding for inter-city rail services, there are unlikely to be funding for HST projects, thus the fate of the proposed HST projects depends on state funding and governors' will rather than federal funding. For an account of HST in the USA, or the lack of it, see Klein (1993) and Thompson (1994).

In Australia, following a scoping study on an east coast HST network (2000 km long), connecting Melbourne, Canberra, Sydney and Brisbane (Department of Transport and Regional Services, 2001), the government decided in 2002 to

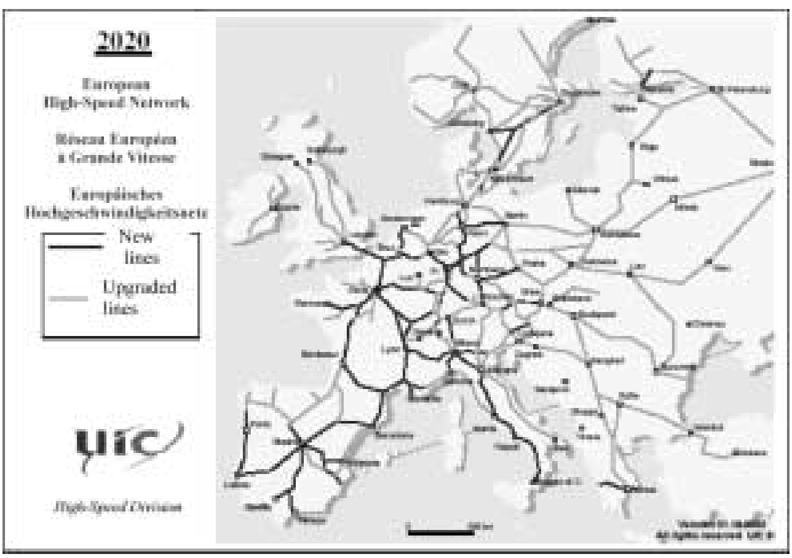

Figure 3. Planned European high-speed train network. *Source:* International Union of Railways (2003)

conclude its investigation after the study showed such a network would be too expensive and that 80% of the funding would have to be public money (Anderson, 2002).

With respect to MAGLEV lines, the Chuo Shinkansen between Tokyo and Osaka is at an advanced planning stage, and it still awaits the government's green light (Takagi, 2005). There are currently no concrete plans for a MAGLEV line anywhere else.

HST as a Mode of Transport

The main reason for the construction of the first Shinkansen and TGV lines was increasing route capacity, and this was also the case for many other lines. In Italy, capacity continues to be the main reason to construct high-speed lines, while the gain in speed will be relatively small, e.g. on the Rome to Naples line. In the UK, spare capacity on the rail network in the 1970s and 1980s was one of the main reasons for not considering HST development when other European countries started developing their HSTs (Commission for Integrated Transport, 2004).

HST lines increase the capacity on the route since they usually supplement existing ones and they free capacity on the conventional network for use by freight and regional passenger services. The direct increase in capacity offered by the HST line is due to the higher frequency, which is feasible due to the higher speed and the most up-to-date signalling systems that allow relatively short headway between trains without compromising safety, and due to the use of long trains with high seat capacities. For example, the first Shinkansen, model 0, had a capacity of 1340 seats and Eurostar trains have 770 seats (International Union of Railways, 2003). The combination of a dedicated high-speed line, high-capacity trains, advanced signalling systems and high-speed enabled JR Central to carry on the Tokaido line 362 000 passengers per day on 287 daily services or a total of 132 million passengers in 2002 (Central Japan Railway Company, 2003). Higher frequency due to a higher speed and improved signalling also means that the introduction of tilting trains on existing tracks will lead to increased capacity on the route.

Reducing travel time is also an important reason for introducing HST services, although not the main reason in most cases. Before the inauguration of the HST in Japan, it took 7 hours to travel between Tokyo and Osaka on the conventional line; it was then reduced to 4 hours following the inauguration of the Shinkansen and it is 2 hours 30 minutes since 1992 (Matsuda, 1993). If the green light will be given to the MAGLEV Chou Shinkansen, travel time between the cities will be further reduced to only 1 hour. The opening of the Spanish HST between Madrid and Seville reduced travel time from 6 hours 30 minutes to 2 hours 32 minutes (European Commission, 1996b) and there are many other similar examples. These time savings have an economic value which the Japanese estimate at approximately €3.7 billion per year (Okada, 1994).

The ability of the HST to cut travel time is determined by the average speed it achieves, which is affected mainly by the number of stops and the different speed restrictions along the route. Therefore, HSTs that have a very high maximum operating speed might still achieve a relatively low average speed and limited travel time savings due to the above. Japan and France provide the fastest services in the world at average speeds of around 260 kph (Takagi, 2005). The Nozomi service on the Tokaido line, which stops only at the main stations along the route, achieves an average speed between Tokyo and Osaka of 206 kph. This is significantly lower than the maximum speed achieved by these HSTs.

HST services can only be attractive on high-demand routes, which is why most HST services will be between city centres. Hence, cities with dense and dominant city centres (in terms of population and/or employment) are more attractive for HST services, unlike large cities which are more dispersed in nature. Since long access journey to the HST station might cancel the time savings the HST service offers (Hall, 1999) there is an incentive to provide more than one station per city. Yet, more stations/stops means a lower average speed and thus a trade-off must be made. Large metropolitan cities that are polycentric in nature can justify more than one HST station, e.g. Tokyo has three stations on the Tokaido line (Tokyo, Shinagawa and Shin-Yokohama). In contrast, the four stations planned on the CTRL (St Pancras and Stratford both in London, and Ebbsfleet and Ashford both in Kent) might not generate enough demand to justify the reduction in average speed and the longer travel time.

Shorter travel times and an increased level of service (a higher frequency and also improved travelling conditions) following the introduction of HST lead to changes in the modal share on the route and to the generation of new demand. The modal share the HST captures depends mainly on the travel time it offers compared with other modes, but also on the cost of travel and travel conditions. Most of the demand shifted to the train mode following the introduction of HST services is from the aircraft and, to a lesser extent, from the car, which was the case on the Paris–Lyon and Madrid–Seville routes (Table 1). However, most of the demand for new HST services is demand shifted from the conventional railway, which has negative consequences for the conventional rail network (Vickerman, 1997). For example, on the Sanyo Shinkansen, 55% of the traffic was diverted to the new line from other rail lines (23% from the aircraft, 16% from the car and bus, and 6% new (induced) demand) (Sands, 1993b). In some cases, the traffic generation effect of new HST services is substantial, such as on the Paris–Lyon and the Madrid–Seville lines (Table 1).

González-Savignat (2004) observes that on relatively short routes the car has the highest modal share on the route, before the introduction of HST services, e.g. 71 and 82% on the Madrid–Zaragoza and Zaragoza–Barcelona routes, respectively,

Table 1. Modal share (%) before and after the introduction of high-speed train services

	TGV, Paris–Lyon line			AVE, Madrid–Seville line		
	Before (1981)	After (1984)	Change	Before (1991)	After (1994)	Change
Aircraft	31	7	–24	40	13	–27
Train	40	72	32	16	51	35
Car and bus	29	21	–8	44	36	–8
Total	100	100	**37**[a]	100	100	**35**[b]

[a]Total traffic increased by 37%. A total of 10% is related to the estimated trend of growth and 27% is considered as induced traffic.
[b]Total traffic increased by 35%.
Source: European Commission (1996).

both 300 km apart. In this case, a similar percentage shift of passengers from car and aircraft to the HST means a greater shift from the car in absolute numbers. Furthermore, González-Savignat notes that in the Spanish experience, the social benefits from the diversion of passengers from the car to the HST are larger than diversion of passengers from the aircraft to the HST.

In summary, by definition all HST lines fulfil the purposes of increasing the route capacity and reducing travel time. Higher capacity and travel speed lead to changes in the modal share, increasing the share of the train at the expense of the aircraft and the private car and diverting passengers from the conventional train to the HST. In addition, the introduction of HST services also leads to the generation of new demand on the route. All these sum the 'transport' effects of the HST. For more evidence on the transport effect of the HST in Europe, see Vickerman (1997).

HST as a Substitute to the Aircraft

Much attention is given to the HST as a substitute to the aircraft and as a possible solution to the congestion and environmental problems faced by the air transport industry, although substituting the aircraft is not the main reason for introducing HSTs (for a literature review of the subject, see Givoni, 2005).

Due to its speed and the location of most HST stations at the city centre, the HST can offer comparable or shorter travel times than the aircraft on some routes and can therefore substitute it. The travel time advantage depends on the average speed of the HST service and the distance each mode has to cover, since trains do not necessarily follow the direct route. For example, on a journey between London and Paris, the HST passes almost 500 km while the aircraft only 380 km. In general, on routes of around 300 km, evidence shows that the introduction of HST services almost leads to a withdrawal of aircraft services (e.g. between Tokyo and Nagoya and between Brussels and Paris), while on routes of around 1000 km and above, the HST ceases to be a good substitute for the aircraft (e.g. between Tokyo and Fukuoka, 1070 km, the HST share of the traffic is only 10%). In between these distances, there is usually direct competition between the modes.

In most cases, competition is also between the operators, the airlines and the railways. This competition means that HST services are added to the aircraft services and not really substituting them. On the London–Paris route the HST captures about 70% of the market (Eurostar, 2005), but the airlines still offer about 60 flights a day just between London Heathrow and Paris Charles de Gaulle (CDG) (Innovata, 2004), two of the most congested airports and one of the most congested routes in Europe (Central Office for Delay Analysis, 2005). However, the situation is different when HST services are introduced at large hub airports (together with the means for a fast and seamless transfer between the aircraft and the HST). In this case, many airlines choose to replace the aircraft with the HST on some routes, leading to a real mode substitution. Lufthansa adopts such mode substitution on the routes from Frankfurt airport to Stuttgart and Cologne, where the aircraft is substituted by the German ICE HST and operated by Deutsche Bahn. Air France uses the HST to replace the aircraft on routes from CDG to Brussels, and on other routes it uses it to complement the aircraft. Furthermore, Airlines such as Emirates, American Airlines and United Airlines use HST services from CDG to complement their flights into Paris (International Air Transport Association, 2003).

An analysis of the potential of the HST to free runway capacity at London Heathrow shows that the HST can lead to travel time savings on ten routes currently served from the airport, which take about 20% of its runway capacity (Givoni, 2005). This requires the airport to be a station on the HST network and the HST services from the airport to achieve an average speed of 250 kph. HST services at London Heathrow can increase the airport's capacity without an additional runway, can increase its level of service on domestic routes (services currently squeezed out by international services) and can allow services to cities that currently have no access to London Heathrow, such as Birmingham and Bristol. In addition, integration of airline and railway services that lead to real-mode substitution follows important elements in the EU transport policy (Commission of the European Communities, 2001). For example, the promotion of aircraft and HST substitution, the integration between the modes of transport and a reduction in the environmental impact of transport operation (especially the impact from aircraft operation). This calls for the emerging European HST network to include stations at the major European airports. The Japanese realized the potential is such integration and the planned MAGLEV Chuo Shinkansen will include, according to plans, stations at Narita and Haneda airports in Tokyo and Kansai airport in Osaka, connecting the three biggest airports in the country (Chuo Shinkansen Ensen Gakusha Kaigi, 2001).

However, considering the forecast growth in demand for air services (Boeing, 2004; Airbus, 2005), the air transport industry would not meet future demand at current runway capacity even if the HST will substitute the aircraft on all routes where it can lead to travel time savings. Nevertheless, the HST has an important role to play in the future of the air transport industry and in relieving the congestion and environmental problems it faces (for the potential of the HST to reduce the environmental impact from aircraft operation, see the seventh section).

In summary, it is through integration between the two modes, and not competition, that the air transport industry will see an opportunity in HST services and will strive to substitute the aircraft by HST (on routes where the latter offers travel time savings).

Spatial and Socio-economic Impacts of the HST

The introduction of HST services results in additional impacts to the 'transport impacts' described above. These impacts include a spatial impact and possible social and economic impacts. Such impacts, especially the economic development impact, are less clear, harder to observe and quantify, and therefore are more controversial.

By changing the relative accessibility of places, the HST creates in effect a different social and economic space. Spiekermann and Wegener (1994) illustrate this impact using time–space maps of Europe that show the European rail network and train travel time in 1993 (Figure 4a) and in 2010 after the implementation of the HST network as envisaged by the International Union of Railway (Figure 4b). The impact is best described by the title of the work: 'The shrinking continent'.

The shorter travel times offered by HST services bring closer cities connected to the HST network and increase their connectivity, the network effect of the HST, which in turn is the driver for the social-economic impacts if these exist. 'The Shinkansen has had strong development effects in Japan at the regional,

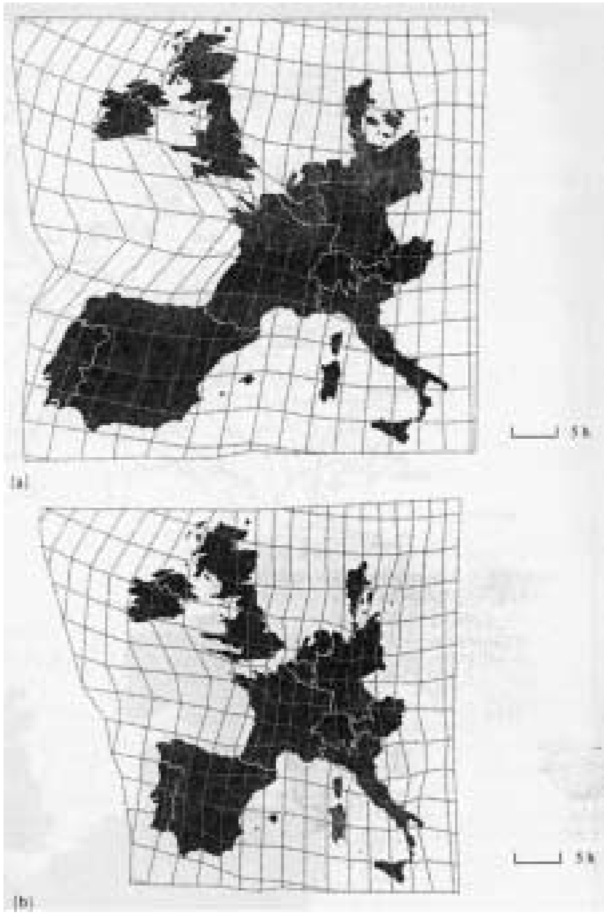

Figure 4. Time–space maps of the rail network in Western Europe: (a) 1991 and (b) 2010, before and after the completion of the high-speed train network. *Source:* Spiekermann and Wegener (1994)

urban and station levels' (Sands, 1993b, p. 267). For example, regions served by the Shinkansen achieved higher population and employment growth rates than those without direct Shinkansen services. However, there are other factors prevailing in these regions that can support and affect such an impact and, therefore, it is unclear if the Shinkansen led to the increase in growth rates or if the Shinkansen was constructed in regions where higher growth rates already existed:

> At the Urban level, the Shinkansen's correlation with population and employment growth rates is clear [but it seems that] the Shinkansen has served to shift growth, not induce it … [and] at the station level, development has varied. (Sands, 1993b, p. 268)

In situations where existing stations were expanded to accommodate the Shinkansen services, little or no development around the station occurred, while in new stations development was dependent on other factors and mainly good transportation links to the new station.

The impact also varied in France. While in Lyon significant growth took place, which was also due to a high demand for office space and good local access to the station, in Le Creusot and Macon, the other new stations on the Paris–Lyon line, little TGV-related activity took place (Banister and Berechman, 2000). Ampe (1995, p. 130) concludes that:

> TGV towns do not benefit automatically from having a TGV station, but that a strategy has to be developed to take advantage of the opportunities offered by improved transport links.

For regions and cities with unfavourable economic conditions, especially in relation to neighbouring regions or cities, a connection to the HST network may even result in economic activities being drained away and overall a negative impact (Van den Berg and Pol, 1997; also Thompson, 1995). Thus, although the introduction of HST services between Paris and Lyon led to significant transport impacts, including changes in modal share, traffic volume and travel behaviour (Bonnafous, 1987), it does not always lead to (positive) economic impacts.

The evidence from different studies on the effect of HST is mixed and the conclusion is that the introduction of HST alone is not sufficient for social-economic impacts to take place. Such impacts depend on other prevailing conditions, and mainly 'the presence of a buoyant local economy that can take advantage of the new opportunities offered by the high-speed rail accessibility' (Banister and Berechman, 2000, p. 282). This is in line with the conclusion that 'transport investment acts as a complement to other more important underlying conditions, which must also be met if further economic development is to take place' (Banister and Berechman, 2000, p. 318). In addition, there is a need for complimentary policies in order to capture any wider socio-economic benefits and also, as noted in the Australian study on the scope for HST, a political vision, leadership and long-term bipartisan political commitment (Department of Transport and Regional Services, 2001).

Positive spatial and socio-economic impacts might occur at places connected to the HST network, yet in places bypassed by the HST (i.e. areas in which the HSTs go through without stopping) negative impacts usually occur because 'high speed infrastructure connects only important cities, but not the space in between them' (Spiekermann and Wegener, 1994, p. 671):

> Without a connection to the European HST, any city's accessibility within Europe could be seriously compromised … both the Shinkansen and the TGV seem to have favoured the large cities at the ends of the lines at the expense of smaller intermediate cities; cities that were bypassed did particularly badly. (Hall, 1999, p. 14)

These effects led Whitelegg and Holzapfel (1993) to conclude that overall the socio-economic impact of the HST is negative.

In summary, there is no agreement on the extent to which the HST infrastructure leads to wider socio-economic impacts in addition to its direct impact as a mode of transport. The evidence is mixed and there seems to be disagreement on whether overall the impacts, if they exist, are positive or negative. Still, the potential for positive economic impacts is an important factor in planning and designing

HST lines (with regard to planning the CTRL, see Norman and Vickerman, 1999), this is probably justified since it seems that it is better to be a node on the HST network than to be bypassed by it.

Environmental Impact of the HST

The impact of HST operations on the environment is usually portrayed in a positive light since it is considered to impact the environment less than other modes of transport, especially the aircraft. However, HST operations lead to negative environmental impacts including local air pollution (LAP), climate change, noise and land take.

HSTs are predominantly electric powered and therefore emissions from HST operations are considered to be linearly related to energy consumption and the sources used to generate the electricity. The higher the level of renewable sources and nuclear power used to generate the electricity, the lower the level of emission associated with HST operations. Usually, it is assumed that the electricity is supplied from the national grid and emission is calculated based on the average electricity generation mix (Commission for Integrated Transport, 2001). The use of electric power also means virtually zero emissions from the HST along the line and at the stations.

The most harmful pollutants related to HST operation are sulphur dioxide (SO_2) and nitrogen oxides (NOx). The former affect the environment mainly by contributing to LAP, and the latter to both LAP and climate change. In general, HST operations are not considered to contribute significantly to climate change, while their contribution to LAP can be significant depending mainly on the levels of SO_2 emission associated with HST operations (Givoni, 2005). These levels depend mainly on the share of coal used to generate the electricity (Button, 1993). Usually, power plants are located away from densely populated areas, which means that the actual impact from HST operation on LAP is lower then suggested by the mix and amount emitted due to the relatively low number of people exposed to the emission.

Locally, along the HST lines, noise nuisance from HST operations can be considered as the main environmental impact of the HST. The level of noise generated depends mainly on the speed of the train. At speeds between 50 and 300 kph, rolling noise is the most important noise source (Brons *et al.*, 2003) and it depends mainly on the smoothness of the wheels and railhead. The high standards of the HST infrastructure (the trains used and the construction and maintenance standards) probably leads to less noise generated from HST operations in comparison with conventional trains running at the same speed. Only at speeds above 300 kph does aerodynamics become the main source of noise. Thus, even for HSTs, rolling noise is probably the dominant source of noise (Brons *et al.*, 2003). At high speeds HST operations result in high levels of noise, yet the impact of this (the actual noise heard and number of people exposed to it) is lower than can be expected since in densely populated areas the speed of the HST is usually at its lowest (due to the distance required for the HST to stop, which means speed is reduced far from the station). In addition, it is possible to 'protect' people from railway noise by building barriers, trenches or tunnels (Commission for Integrated Transport, 2001; Nijland *et al.*, 2003).

Since the introduction of HST services often involves the construction of new railway lines, land-take is an important environmental impact related to HSTs.

Land-take leads to other environmental impacts including habitat loss, fragmentation and community severance (Commission for Integrated Transport, 2001).

In comparison with other modes, HST operations result in less environmental impact than aircraft operations in terms of LAP and climate change impacts on all the routes where the modes compete (Givoni, 2005). In terms of LAP, the advantage of the HST depends mainly on the level of SO_2 emissions related to HST operations. The impact of aircraft operations on climate change is higher than the impact of the HST due to higher emission rates of carbon dioxide and NOx and the fact that NOx emissions at high altitude effect climate change much more than emissions at ground level, by a factor of more than 100 (Archer, 1993; Dings *et al.*, 2002). With regard to noise pollution, it is less clear whether the aircraft or the HST leads to more noise pollution, and analysis on a route basis is required (Commission for Integrated Transport, 2001), yet it is easier to provide protection from railway noise than from aircraft noise.

Less evidence is available on whether an HST or a car journey has more impact on the environment in terms of emissions (i.e. LAP and climate change). Data from Van Essen *et al.* (2003) and the Commission for Integrated Transport (2001) suggest that HST operations result in lower energy consumption and less emissions, but because HST operations result in more SO_2 emissions, it might result overall in a higher impact on the environment through a higher LAP impact (since different pollutants have different impacts and comparing only emissions might be misleading).

In conclusion, HST infrastructure and operations certainly result in adverse impacts on the environment, mainly by affecting LAP, causing a noise nuisance and consuming land. LAP impacts are significantly reduced if renewable and nuclear energies are used to generate electricity for the HST. There is also evidence that HST operations impact the environment less than the aircraft and the car when these modes are compared on the same basis. However, whether the introduction of new HST infrastructure and services leads to environmental benefits is less clear. This depends on the balance between the substitution effect (how many passengers using the HST were shifted from the aircraft and the car) and the traffic generation effect (how much new demand was generated by the HST). In addition, the environmental benefits gained from the substitution effect depend on how the freed capacity (on the road and runway) is used. If this capacity is used, e.g. for the airlines to offer more (long-haul) flights, then mode substitution will increase the environmental impact.

Cost of the HST Infrastructure

The advantages of the HST, and mainly the increase in capacity it provides, must be weighed against not only the demand for HST services, but also the cost of providing it. In general, investments in the HST infrastructure are always very high.

The cost of the HST infrastructure varies a lot between countries and lines (Figure 5). Variations are attributed mainly to the terrain along the route, which determines the need for bridges and tunnels; to whether a dedicated line is built all the way to the city centre; and the proportion of densely populated areas through which the line passes, which in addition to bridges and tunnels means high land costs. The cost also varies a lot with the general economic characteristics of the country that affect the cost of land and labour (the planning, management, engineering and construction workforces). An increased awareness of the environmental impacts of the HST and the need to mitigate these is another significant cost element in the construction of HST lines.

The construction of routes through tunnels or over viaducts, for example, is considered to be four-to-six times more expensive per kilometre than construction over flat land (Commission for Integrated Transport, 2004). The HST line connecting London and the Channel Tunnel (the CTRL) is being constructed in two stages and is a good example of the sensitivity of the cost to the line's characteristics. The first stage, which was completed in 2003, cost €37 million per km, while the second stage, which is scheduled to open in 2007, and which brings the HST to the centre of London and has 85% of its length in the form of tunnels (including two new underground station, about 1 km long), is expected to cost €122.5 million per km. Overall, the 109-km line is expected to cost €7.4 billion (Channel Tunnel Rail Link, 2005), and it is the most expensive HST line to be built to date (Commission for Integrated Transport, 2004) (Figure 5).

It is also difficult, for the reasons stated above, to compare the costs of different railway technologies. In general, a new, dedicated HST line is expected to cost more than an upgraded line (e.g. for use by tilting HSTs), but it will provide a much higher capacity. Therefore, a trade-off is required between the capacity provided and its cost. However, in the case of the UK, the upgrade of the West Coast Main Line between London and Manchester proved to be more expensive than a new, dedicated HST line along the route (Commission for Integrated Transport, 2004). MAGLEV lines are probably the most expensive HST infrastructure. The estimate for the Chou Shinkansen is between €123 million and €147 million per km (Chuo Shinkansen Ensen Gakusha Kaigi, 2001).

Conclusions

The modern HST was developed mainly to substantially increase railway capacity on the route. This was achieved, in part, through high-speed operation, which also

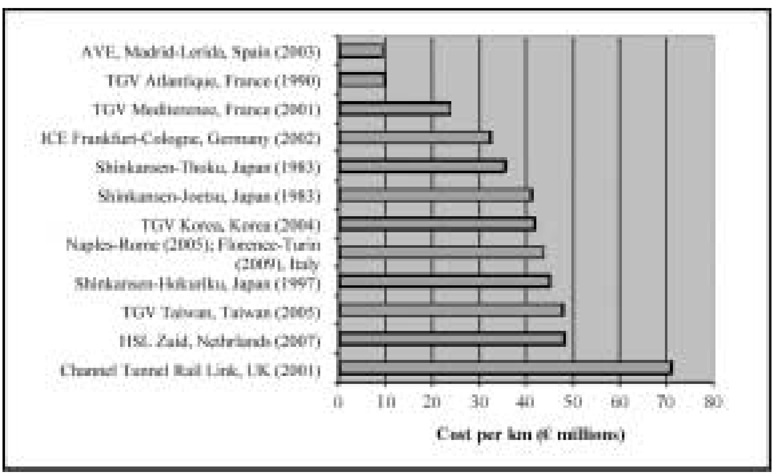

Figure 5. High-speed line construction cost and (planned) opening date (€/km). *Source:* based on Commission for Integrated Transport (2004) (no reference is made to the year to which the estimates relate)

led to substantial reduction in travel times and it improved the competitiveness of the train against other modes. Thus, the justification for HST relies first on very high demand, which currently is not properly served by available (railway) transport services. The long distance between two cities is another important requirement to justify HST, but it is not sufficient on its own to justify the expensive investment.

An HST line is considered to be commercially viable:

> between major urban agglomerations, with over one million population … [when] such agglomerations are disposed along linear corridors, with cities spaced at approximately 125-mile (200-km) intervals. (Hall, 1999, pp. 6–7)

Vickerman (1997) adds the requirement for demand of between 12 million and 15 million railway passengers a year between two urban centres to justify HST. Even if many HST lines deviate from this description, it still holds as the base for HST operation, especially for a profitable one (as proved on the Tokyo–Osaka line (Kasai, 2000) and the Paris–Lyon line (Vickerman, 1997).

At present, based on the existing evidence, investment in HST infrastructure could not be supported based on the expectations for economic development benefits. Therefore, the rationale for investments in HSTs must be their impact as a mode of transport, i.e. their ability to serve the railway market better than the conventional railway, and their ability to substitute other modes. To be an effective substitute to the aircraft, the HST network must include stops at the major airports to ensure full integration between HST and aircraft services. With regard to the potential of the HST to substitute the car, it seems that not enough research has been devoted to this question, although this might be an important effect of the HST (on relatively short routes of less than 300 km).

There is no doubt that the HST can deliver socio-economic benefits and mainly improve the accessibility of the cities it serves. Yet, this presents a dilemma to policy-makers and planners. To increase the overall benefits of the HST (and decrease its negative effects), it should serve many cities and include many stops, but more stations on an HST line lead to a lower average speed and thus to lower capacity on the route and a longer travel time, reducing the benefits of the HST. This also emphasizes the undue importance given to the maximum operation speed of the HST when average speed is the factor to which attention should be given.

The principle of the HST is defined by some as being 'twice as fast as the auto, half as expensive as air' (Sands, 1993a, p. 205) or 'to provide the transport services to its users (passengers) at the speed twice higher than a car and twice slower than the plane' (European Commission, 1996b, p. 88). Both definitions focus on the HST as a substitute to other modes, while this is only part of the HST role. In addition, the price and travel time (in comparison with air services) components of the definitions do not seem to hold in many cases. Following this review, the following definition for HST is suggested: high capacity and frequency railway services achieving an average speed of over 200 kph.

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References

Airbus (2005) *Global Market Forecast 2004–2023.* December. Available at http://www.airbus.com/pdf/media/GMF2004_full_issue.pdf (accessed 6 June 2005).

Ampe, F. (1995) Technopole development in Euralille, in: D. Banister (Ed.) *Transport and Urban Development*, pp. 128–135 (London: E&FN Spon).

Anderson, J. (2002) Government ends scoping study on east coast very high speed train network. Media release by The Hon. Johan Anderson MP, Australian Deputy Prime Minister, Minister for Transport and Regional Services, 26 March. Available at http://www.ministers.dotars.gov.au/ja/releases/2002/march/a35_2002.htm (accessed 20 July 2005).

Archer, L.J. (1993) *Aircraft Emissions and the Environment: CO_x, SO_x, HOx & NOx.* Papers on Energy and the Environment (Oxford: Oxford Institute for Energy Studies).

Banister, D. and Berechman, J. (2000) *Transport Investment and Economic Development* (London: UCL Press).

Banister, D. and Hall, P. (1993) The second railway age, *Built Environment*, 19(3/4), pp. 157–162.

Boeing (2004) *Current Market Outlook 2004.* Boeing Commercial Airplanes. Available at http://www.boeing.com/commercial/cmo/pdf/CMO2004.pdf (accessed 20 June 2004).

Bonnafous, A. (1987) The regional impact of the TGV, *Transportation*, 14, pp. 127–137.

Bouley, J. (1986) Innovative areas: high speeds, in: ECMT, European Conference of Ministers of Transport, *European Dimension and Future Prospects of the Railways* (Paris: ECMT).

Brons, M., Nijkamp, P., Pels, E. and Rietveld, P. (2003) Railroad noise: economic valuation and policy, *Transportation Research Part D*, 8, pp. 169–184.

Button, K. (1993) *Transport, The Environment and Economic Policy* (Aldershot: Edward Elgar).

Commission of the European Communities (2001) *European Transport Policy for 2010: Time to Decide.* COM(2001)370, September (Brussels: CEC) Available at http://europa.eu.int/comm/off/white/index_en.htm (accessed 15 February 2002).

Central Japan Railway Company (2003) *Central Japan Railway Company Data Book 2002* (Nagoya: CJRC).

Commission for Integrated Transport (2001) *A Comparative Study of the Environmental Effects of Rail and Short-haul Air Travel.* September (London: CfIT).

Commission for Integrated Transport (2004) *High Speed Rail: International Comparisons.* February (London: CfIT).

Chuo Shinkansen Ensen Gakusha Kaigi (2001) *Linia Chuo Shinkansen de Nihon ha Kawaru* [The Future Change in Japan by Linear Chuo Shinkansen] (Tokyo: PHP).

Central Office for Delay Analysis (CODA) (2005) *Delays to Air Transport in Europe Annual Report 2004* (Brussels: Eurocontrol).

Channel Tunnel Rail Link (CTRL) (2005) Available at http://www.ctrl.co.uk/building (accessed 6 June 2005).

Department of Transport and Regional Services (2001) *East Coast Very High Speed Train Scoping Study*, November (Sydney: DTRS, Australian Government. Available at http://www.dotars.gov.au/transinfra/vhst/contents.aspx#contents (accessed 20 July 2005).

Dings, J. M. W., Wit, R. C. N., Leurs, B. A., De Bruyn, S. M., Davidson, M. D. and Fransen, W. (2002) *External Costs of Aviation*, February (Delft: CE Delft).

European Commission (1996a) Council Directive 96/48/EC of 23 July 1996 on the interoperability of the trans-European high-speed rail system, *Official Journal*, L23, 17 September, 0006–0024.

European Commission (1996b) *Interaction between High Speed and Air Passenger Transport—Interim Report.* Interim Report on the Action COST 318, April (Brussels: EC).

European Commission (2001) *Trans-European Transport Networks* (Brussels: EC) Available at http://www.europe.eu.int/comm/transport/themes/network/english/tentpp9807/tentpp9807.html (accessed 18 February 2001).

Ellwanger, G. and Wilckens, M. (1994) High speed for Europe, *Japan Railway and Transport Review*, 3, pp. 17–25.

Eurostar (2005) *Record Passengers … Record Market Share … Record Punctuality* (London: Eurostar) Available at http://www.eurostar.com/dctm/jsp/subhome/detail.jsp?page=news&id=09001a598017d75b (accessed 19 February 2005).

Federal Railroad Administration (2005) *High-Speed Ground Transportation* (Washington, DC: FRA) Available at http://www.fra.dot.gov/us/content/31 (accessed 6 June 2005).

Giuntini, A. (1993) High speed trains in Italy, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 55–65 (Hawes, North Yorkshire: Leading Edge).

Givoni, M. (2005) Aircraft and high speed train substitution: the case for airline and railway integration. PhD thesis, University College London.

Gómez-Mendoza, A. (1993) History and the AVE, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 48–54 (Hawes, North Yorkshire: Leading Edge).

González-Savignat, M. (2004) Will the high-speed train compete against the private vehicle?, *Transport Reviews*, 24, pp. 293–316.

Hall, P. (1999) High-speed train and air: competitive or complementary? Paper presented at the Lake Arrowhead Transportation Symposium, 25 October 1999.

International Air Transport Association (2003) *Air/Rail Intermodality Study*, February (London: IATA).

Innovata (2004) *Innovata Flight Schedules* (Innovata) Available at http://www.quicktrip.com/flightbase/schedules (12 March 2004).

International Railway Journal (2004) High speed rail gets a boost, *International Railway Journal*, February. Available at http://www.railjournal.com/A/xthismonth.html (accessed 4 March 2004).

Japan Railway and Transport Review (2005) Efforts to increase Shinkansen speeds, *Japan Railway and Transport Review*, 40, pp. 34–35.

Kasai, Y. (2000) A history of the development of Japanese railway networks, *Japan and the World Economy*, 12, pp. 89–93.

Klein, M. (1993) America's lost opportunity, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 66–77 (Hawes, North Yorkshire: Leading Edge).

Matsuda, M. (1993) Shinkansen: the Japanese dream, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 111–120 (Hawes, North Yorkshire: Leading Edge).

Nijland, H. A., Van Kempen, E. E. M. M., Van Wee, G. P. and Jabben, J. (2003) Costs and benefits of noise abatement measures, *Transport Policy*, 10, pp. 131–140.

Norman, C. and Vickerman, R. (1999) Local and regional implications of trans-European transport networks: the Channel Tunnel Rail Link, *Environment and Planning A*, 31, pp. 705–718.

Okada, H. (1994) Features and economic and social effects of the Shinkansen, *Japan Railway and Transport Review*, 3, pp. 9–16.

People's Daily (2004) Rail track beats MAGLEV in Beijing–Shanghai high speed railway. *People's Daily* Online, 18 January. Available at http://english.peopledaily.com.cn/200401/16/eng20040116_132743. (accessed 18 July 2005)

Polino, M. N. (1993) The TGV since 1976, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 38–47 (Hawes, North Yorkshire: Leading Edge).

Raoul, J. C. (1997) How high-speed trains make tracks, *Scientific American*, 227(4), pp. 100–105.

Sands, B. (1993a) The German Inter City Express, *Built Environment*, 19(3/4), pp. 203–214.

Sands, B. (1993b) The development effects of high-speed rail stations and implications for Japan, *Built Environment*, 19(3/4), pp. 257–284.

Sone, S. (1994) Future of high-speed railways, *Japan Railway and Transport Review*, 3, pp. 4–8.

Spiekermann, K. and Wegener, M. (1994) The shrinking continent: new time–space maps of Europe, *Environment and Planning B: Planning and Design*, 21(6), pp. 653–673.

Takagi, R. (2005) High speed railways: the last 10 years, *Japan Railway and Transport Review*, 40, pp. 4–7.

Taniguchi, M. (1993) The Japanese magnetic levitation trains, *Built Environment*, 19(3/4), pp. 235–243.

Thompson, I. B. (1995) High-speed transport hubs and Eurocity status: the case of Lyon, *Journal of Transport Geography*, 3(1), pp. 29–37.

Thompson, L. S. (1994) High Speed Rail (HSR) in the United States—why isn't there more?, *Japan Railway and Transport Review*, 3, pp. 32–39.

International Union of Railways (UIC) (2003) Available at http://www.uic.asso.fr (accessed 21 July 2003).

Van den Berg, L. and Pol, P. (1997) The European high-peed train network and urban development. Paper presented at the European Regional Science Association 37th European Congress, Rome, Italy, August 1997.

Van Essen, H., Bello, O., Dings, J. and Van den Brink, R. (2003) *To Shift Or Not To Shift That's the Question: The Environmental Performance of the Principal Modes of Freight and Passenger Transport in the Policy-Making Context*, March (Delft: CE Delft).

Vickerman, R. (1997) High-speed rail in Europe: experience and issues for future development, *Annals of Regional Science*, 31, pp. 21–38.

Whitelegg, J. and Holzapfel, H. (1993) The conquest of distance by the destruction of time, in: J. Whitelegg, S. Hultén and F. Torbjörn (Eds) *High Speed Trains: Fast Tracks to the Future*, pp. 203–212 (Hawes: North Yorkshire: Leading Edge).