The Japanese Shinkansen

Catalyst for the renaissance of rail

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At the entrance to the Shinkansen,[1] at Tokyo Central Station, a dignified plaque written in both Japanese and English, proclaims:

New Tokaido Line
Product of the wisdom and effort of the Japanese people
Tokyo-Shin Osaka 515 km
Work started 1959 20 April
Opened to traffic 1964 1 October.

As an indication of the unity of purpose and of the pride which the Japanese people felt for this achievement the inscription on this plaque can hardly be bettered. The opening of the line coincided with the Tokyo Olympic Games, a visible symbol to the world that Japan had emerged from the dark days of the war and post-war depression. Indeed, from about that date the Western world began to look to Japan as a model for successful manufacturing, based on consensus and harmony with the people; Western businesses asked for advice and began to wonder how the 'economic miracle' had been achieved. However, the railway world was initially somewhat muted in its praise for the Shinkansen, and although the round-nosed streamlined trains rapidly earned the affectionate 'Bullet Train' title with the public around the world, it was to be some time before railway administrations recognised the scale and success of the Japanese achievement.

In order to put the Shinkansen into historical context, this article describes briefly the history of the development of Japanese railways up to 1964, before discussing the events leading up to the birth of the Shinkansen. A description of the many developments of the Shinkansen and the expansion of the network follows, leading to a discussion of the impact of the Shinkansen on Japanese society. The article concludes with some remarks on the current status and future prospects of the high-speed railway in Japan and elsewhere.

Development of Japanese railways up to 1964

The industrial revolution arrived in Japan with the new dawn of the Meiji period (1868–1912). Japan emerged from 200 years of almost complete

isolation from the rest of the world, with a rudimentary transport system which relied on man or horse power over a primitive network of roads and tracks. Thirty kilometres a day was considered to be good progress. It is necessary to remember that Japan is a very densely forested, mountainous country; even today only slightly more than 20 per cent of the land area is considered habitable. Furthermore, the country extends over some 2,000 km, from the northern island of Hokkaido, with a sub-arctic climate, to the subtropical island of Kyushu in the south (see Figure 1 for the geographical layout of Japan). The Meiji government recognised that the only way to compete with and to protect itself from the West was to enthusiastically import technologies: the telegraph came in 1869, the Nagasaki–Shanghai submarine cable connected Japan with the outside world in 1872 and the telephone arrived in 1877.[2]

Work on the first railway, connecting Shinagawa (in Tokyo) with Yokohama, a rapidly developing international port, started in 1870.[3] The technology was entirely British: it is said that the emperor Meiji, on the formal opening of the

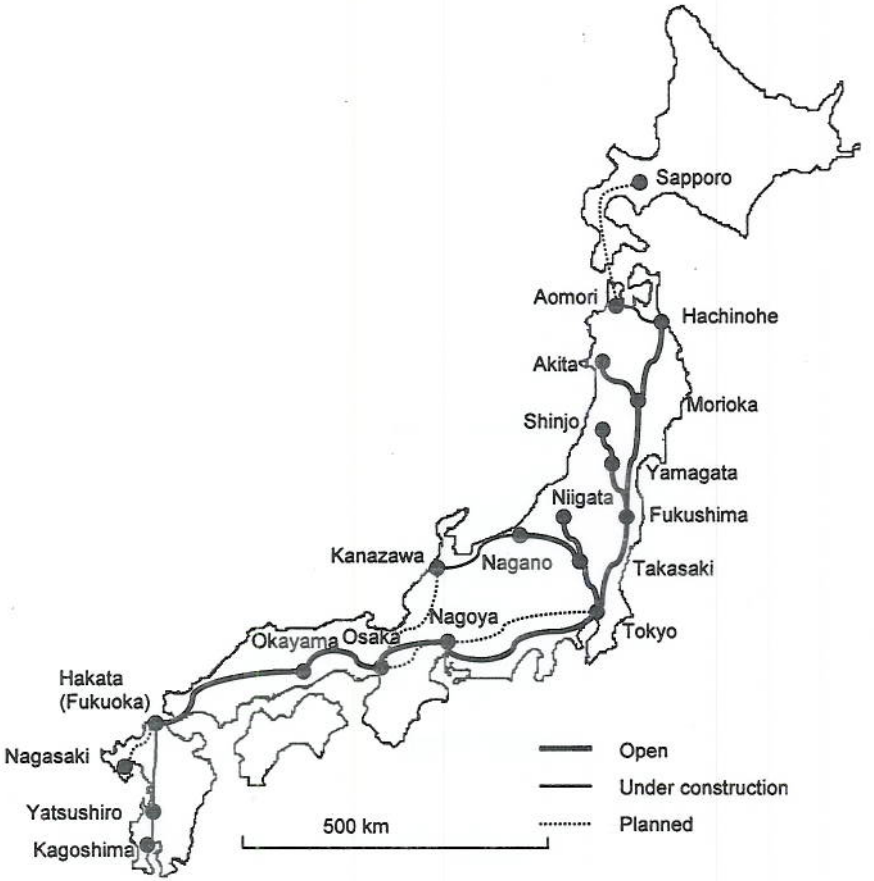

Figure 1 The Shinkansen routes

line on 14 October 1872, rode in a coach built in Birmingham, its Fox bogies from Leeds ran over rails rolled in Sheffield and the interior contained cushions of Lancashire cotton trimmed with Nottingham lace. The line, which had been built by the Englishman Edmund Morel, was operated by British drivers and fuelled by Welsh coal.[4] Morel, reputedly because of his earlier experience of railway construction across similar mountainous terrain in New Zealand, built the railway to the economic narrow gauge of 3 ft 6 in. (1,067 mm), a gauge which is still used today on the so-called conventional lines (i.e. non-Shinkansen lines) in Japan. The Tokyo to Yokohama line was only 29 km long. By 1877 Japan had a total of merely fifty miles (80 km), compared with 16,000 km in France and nearly 24,000 km in Britain.

After these small and late beginnings, the railway slowly spread to the outlying areas of Japan. The island of Hokkaido adopted American railway technology, and on this northern outpost coal became the most important freight. The trunk lines spread from the Tokyo centre, whilst the main route, the approximately 500 km long Tokaido, was completed in 1889, linking Tokyo and Yokohama, via Nagoya and Kyoto, with Osaka and the port of Kobe. The region along this route has grown to occupy an ever more dominant role in the country's government, financial, manufacturing and cultural life and has taken the name the 'Tokaido route' from the ancient track connecting these centres of the heartland of Japan.

Although the earliest railways were state-promoted and state-owned, privately managed lines played an important role in the expansion of the network. In 1906 the government, recognising the strategic military importance of the railways, nationalised the private main lines, and the newly created Japanese Imperial Railway then had a network of just over 7,000 km. Some local lines remained in private ownership and others were built later to serve the rapidly expanding urban areas, particularly around Tokyo, Nagoya and Osaka in the 1920s and 1930s. These lines remain in private hands today and in terms of volume movement and revenue per kilometre of track are amongst the most successful railways in the world.

The early decades of the twentieth century saw a continuing expansion of the railway network without serious competition from the automobile until as late as the 1960s. Some limited electric traction was introduced as early as 1895, but its use was largely confined to urban railways (the subway in Tokyo first operated in 1927) until much later. Although limited numbers of diesel trains were operated, indigenous coal was Japan's main power source and steam traction was dominant well into the early 1970s. One interesting technical feature which is often overlooked was the introduction of automatic couplers on all freight wagons in 1926. Well in advance of similar moves in Europe, this change increased both efficiency and safety, the latter having become the hallmark of Japanese railway operations in the last few decades.

The Tsubame ('Swallow') expresses, introduced in 1930, reduced the time from Tokyo to Kobe to nine hours – a significant reduction from the twenty hours required in 1889 and fifteen in 1903. Infrastructure improvements included the completion of double track over the Tokaido route in 1913 and

the opening of the 7.8 km long Tanna tunnel in 1934, which shortened the route by omitting a detour round the mountains between Atami and Numazu. Throughout this period, more and more traffic was carried along this vital artery. The need for expansion of capacity was recognised, and work actually started on a new standard-gauge (4 ft 8½ in. or 1,435 mm) line in 1940. A key part of the motivation behind this new line was to link Tokyo with the western part of Japan, which, in turn, linked up with Japanese-held territory in China and Korea. It was planned that fast electric trains, already nicknamed *dangan ressha* (Bullet Trains), would speed along this line towards Kyushu and perhaps even through an undersea tunnel to the Asian mainland via the Korean peninsula. Although the undersea Kanmon tunnel was completed between Honshu and Kyushu in 1942, thus directly linking two of Japan's four main islands for the first time, the Pacific war had started in 1941 and it was to be some time before the railway network could be further expanded.

When the Occupation forces arrived in Japan in 1945, they were stunned to see the extent of urban destruction caused by bombing.[5] Over sixty cities were damaged and the railways had suffered to an extent that made their continued operation difficult. Resources had been absorbed by the war effort, with the result that both equipment and infrastructure were in a grievous state. Nevertheless, the railways continued to run; indeed, they were the only reasonably practical form of transport available to the vast majority of the impoverished people. Overcrowding was the norm, but perhaps the fact that the railways struggled through gave them a special place in the hearts of the Japanese people. In these desperate days there was an unprecedented level of labour unrest, which occasionally led to acts of sabotage on the railway, strikes were common and railway accidents frequent. Overall, however, the Occupation period (1945–52) has been subsequently judged by many to have been a success, and order was gradually imposed or emerged from within. A key element of the economic democratisation forced by General MacArthur during the Occupation period was the reorganisation of the nation around capital accumulation and industrial reinvestment. This policy, allied with 'long-termism', was a major force in producing the economic 'miracle' which began in the 1960s.[5]

In 1949 the State-owned railway system became Japanese National Railways (JNR), with over 21,000 km of route, whilst the remaining, largely urban, private railways ran over some 5,500 km. JNR was founded as a public corporation, but in reality there was always some ambiguity in its relationship with the government and it was by no means fully autonomous. Naturally, modernisation and improvement were slow at first but rapidly gathered pace as the economy expanded during the Korean War (1950–53).

Events leading to the birth of the Shinkansen

By the early 1950s the Tokaido line had enhanced its position as the main artery of Japan. Although it was only 3 per cent of the railway system by length, it carried 24 per cent of JNR's passenger traffic and 23 per cent of its

freight, and the rate of growth was higher than any other line in the country. By 1956 electrification had been completed from Tokyo to Osaka. New 'Kodama' trains cut the time from Tokyo to Osaka to six and a half hours, but demand was so large that tickets regularly sold out within ten minutes of being put on sale one month in advance of travel. Projections of the increase in passenger traffic, linked with economic growth, indicated that traffic was likely to double by 1975 and that this growth could be accommodated only by a new line; the question was, what form should the new line take?

One technical advantage that the post-war period brought to Japan is only relatively recently becoming recognised.[6] Scientific and engineering initiatives which in the West were devoted to military projects in aviation and the development of atomic power were adapted in Japan to peaceful industrial uses. Teams of highly trained and capable engineers were recruited into the railway industry. Some of these men had been involved with Japan's first 'super-express' trains, which were introduced in Manchuria during the Japanese occupation in the 1930s. Accessible histories of the development of streamlined, air-conditioned, luxury high-speed trains, running on standard gauge, remain to be written, but there is no doubt that this experience was invaluable when the plans for the New Tokaido Line were being formulated.

In the early 1950s the phrase 'railway downfall theory' was much used in Japan (and elsewhere). Just as horse-drawn carriages, canals and sailing ships had been superseded by trains and steamships early in the nineteenth century, it was presumed that the latter half of the twentieth century would see the supremacy of automobiles and aeroplanes, so that the railway was thought to be on the road to decline and extinction. In Japan at the time, automobile production was gradually increasing, the construction of highways was about to start and civil aviation had been resumed. Many JNR personnel shared this negative view, but it was overcome by the vision and leadership of a small number of managers, central amongst whom were Hideo Shima, chief engineer of JNR, and Shinji Sogo, the newly appointed president.

Various alternatives were considered. The most obvious one, additional Japanese-gauge tracks either parallel to the existing ones or on a new alignment, was found to be impracticable largely because of the congestion of new buildings along the route, the large number of level crossings and the radii of the existing curves preventing high-speed running. However, a completely new line would allow a standard-gauge track to be laid, free from crossings, with shallow curves and, crucially, free from the constraints of older facilities and 'released from JNR old habits'.[7] In May 1957 a public lecture was given at the JNR-owned Railway Technical Research Institute (RTRI) to commemorate its fiftieth anniversary. The gist of the lecture, 'The High-speed Railway of the Future', based on studies undertaken at RTRI, was the proposal to create completely new technology and standards for track, safety, trolley wire, etc., far in advance of traditional railway concepts. It was suggested that it was possible to cover the 550 km between Tokyo and Osaka in three hours by electric train, at a maximum speed of 250 km per hour. It is worth noting that boosted capacity, rather than increased speed, was the primary driver. Early

plans included the provision of freight trains, but these were soon excluded, thus contributing to a further decline in rail's share of freight in Japan, which is now very small (about 5 per cent of tonne kilometres).

A commission under the Minister of Transport was instituted which proposed the building of a new Tokaido line of standard gauge, and in December 1958 the government accepted the plans, aiming at completion within the remarkably short period of five years. During this time, many new technologies would have to be developed, simultaneously with major civil engineering work, including the building of the Shin-tanna tunnel, some 7,950 m long, to unblock a major bottleneck of the whole line.

Some key technology features eventually decided upon included: the use of 25 kV a.c. power to overcome the low power limitation of the 1,500 V d.c. supply used on the existing electrified narrow-gauge system, the abolition of lineside signals, with all necessary indications for the driver inside the cab, the adoption of a comprehensive system of Automatic Train Protection, the use of distributed power along the axles of the train to reduce the heavy axle loads under single power cars and new types of track, which in many places ran along considerable lengths of low viaduct.

The cost of constructing the Shinkansen was at first estimated at nearly ¥200 billion, which was raised in the form of a government loan, railway bonds and a low-interest loan of US$80 million from the World Bank. One World Bank criterion excluded experimental techniques from loans. Mr Shima was able to persuade the World Bank that the Shinkansen would include no experimental features, but was an integration of proven advanced technologies achieved under an existing JNR 'Safety First' programme. The decision to construct a standard-gauge Shinkansen at the end of the 1950s owed much to Shinji Sogo, the president of JNR. To improve the Tokaido line, he insisted on adopting the standard gauge despite much opposition. His reason was that he firmly believed the international standard gauge was indispensable to radical improvement of Japanese railways. To ensure government approval for construction of the Shinkansen, JNR set the original budget on the low side. As the budget shortfall became clear, Sogo resigned in 1963 to take responsibility. However, much of the political credit for the Tokaido Shinkansen goes to him. Costs, however, rose in a way which is now familiar, and by the time of the line's opening had doubled. Sogo was not reappointed as JNR president and Mr Shima resigned with him in 1963.[8] Thus neither the political father of the Shinkansen, Mr Sogo, nor its technical father, Mr Shima, attended the formal opening in 1964. It is worth noting that the World Bank loan was repaid in 1982, eighteen years after the opening of the line.

Throughout the period of promotion and subsequent construction of the Shinkansen, the government supported the Ministry of Transport, which, in turn, supported its own JNR. This is an early example of the 'Japan Inc.' solidarity which contributed so much to Japan's rapid post-war growth and contrasts strongly with the short-term financial control often exercised by Western governments, even on their own projects designed to boost national infrastructure.[9]

Development and expansion of the Shinkansen network

Ridership on the Tokaido Shinkansen built up rapidly after its opening. The hundred millionth passenger was recorded shortly after construction work on the westward extension to Kobe and Okayama began in March 1966. The terrain on this section is such that 58 per cent of the route is on viaducts or bridges and 35 per cent is in tunnels. This naturally increased the construction cost, but allowed radii to be eased to a minimum of 4 km instead of the 2.5 km on the earlier line. The maximum speed could therefore be raised to 260 km hr shortly after the line opened in March 1972. Major civil engineering problems were encountered on the further extension west to Kyushu Island, including the Shin-kanmon tunnel of 18.7 km linking Honshu and Kyushu, which took four years to build. By March 1975 it was possible to travel the 1,069 km from Tokyo to Hakata in six hours and fifty-six minutes, shortly afterwards reduced by a further sixteen minutes.

Back in 1969 a National Development Plan had been approved by the Cabinet, which included the construction of a Shinkansen network of 7,200 km.[10] As the years passed, the plan began to turn into reality. By 1982 the Tokoku and Joetsu services started operation. Both departed initially from Ueno station in Tokyo, but were later connected with Tokyo station by underground tracks. The Tokoku service runs north-east up Honshu island to Sendai and Morioka. The eventual plan is to extend this line through the 53.9 km long Seikan tunnel, the longest undersea tunnel in the world, opened to conventional trains in 1988, through to Sapporo on Hokkaido. The north coast was reached by the Morioka to Hachinohe extension, opened in December 2002. The Joetsu service goes north into the 'Snow Country' where the north coast of Honshu faces the China Sea. Particular engineering counter-measures, including spraying heated water to clear the tracks, were taken to allow high-speed operations in unfavourable snow conditions, but the snow is a major attraction to many residents of the Tokyo area, who flock north to enjoy winter sports, including a newly built resort, Gala Yuzawa, directly served by a short spur of the Shinkansen.[11] It is largely believed that the impetus for proceeding with the Joetsu line, in advance of more economically favourable options, came from pressure applied by Prime Minister Tanaka, later to be disgraced in a financial scandal, who represented the area around Niigatta at the northern end of the line.

The most recent Shinkansen route to be completed was the 117 km long branch from Takasaki, on the Joetsu line, to Nagano, built to serve the Winter Olympic Games held in Nagano in 1998. All the original Shinkansen lines were self-contained, and extensions of journeys necessitated the transfer of passengers to trains on conventional narrow-gauge lines. In July 1992 through services were initiated from Fukushima on the Tohoku line to Yamagata and later, in December 1999, extended to Shinjo. Farther north, in March 1997, services were extended from Morioka to Akita. This through running was achieved by laying a third rail extending the existing narrow-gauge track to the standard gauge of the Shinkansen, whilst improvements

were made to level crossings and some curves were eased. Nevertheless, the maximum speed of 130 km hr of the Shinkansen on these hybrid extensions is markedly less than on 'proper' Shinkansen tracks.

On the southern island of Kyushu construction work is well under way on the new line between Kagoshima and Shin-Yatsushiro, with services scheduled to start in 2004, and the continuation to Hakata, linking with the Sanyo Shinkansen, due to open in 2012. These developments are summarised in Table 1. Two features have characterised the Shinkansen's development since its inauguration. The first is the ever-increasing frequency of operation as passenger numbers have grown; the second is the continual development of new equipment to enable higher speeds to be attained. This latter has accelerated over the last decade, since the break-up of JNR into smaller companies in 1987, in preparation for full-scale privatisation.

Table 1 The development of the Shinkansen system

Line	*From/to*	*Length (km)*	*Opening date(s)*	*Max. speed (km hr)*
Tokaido	Tokyo–Shin Osaka	515	1964	270
Sanyo	Shin Osaka–Hakata	554	1972/75	300
Tohoku	Tokyo–Morioka	593	1982/85	
			1991/2002	275
Joetsu	Tokyo–Niigata	270	1982	275
Hokuriku	Takasaki–Nagano	117	1997	260
Yamagata	Fukushima–Shinjo	149	1992/99	130
Akita	Morioka–Akita	127	1997	130

Concerning the privatisation, despite the many excellent aspects of the service offered to passengers, and on the Shinkansen services in particular, over the JNR network as a whole the financial situation deteriorated sharply between 1964 and 1987 until it reached crisis proportions. For most of this period JNR suffered from overmanning and union disruption, whilst considerable investment had been made in new infrastructure. By 1987 the debt had reached ¥37.1 trillion, some 10 per cent of Japan's GNP. ¥25.4 trillion of this total was generated by JNR itself, another ¥5.1 trillion was outstanding debt on large railway infrastructure projects, including ¥1.1 trillion for the construction of the Seikan tunnel to Hokkaido and ¥1.8 trillion for the Joetsu Shinkansen. As a consequence of this situation, from 1987 JNR was divided into six vertically integrated companies following the geographical divisions of Japan, that is, three major companies on the main island of Honshu, JRs Central, East and West, three island companies, JRs Kyushu, Shikoku and Hokkaido, together with a single national rail freight company. Of these new companies, JR East and JR Central are the giants, whilst the three island companies suffer from the consequences of low density and scattered population, leading to the problems of contraction familiar to railway companies in many parts of the world. It was envisaged that these companies

would eventually become truly private companies, free from political interference. Whilst the larger companies have sold some shares, the smaller companies have not become profitable enough to start down the flotation road. Thus the government still has a strong presence, and the 'quasi-privatisation' is far from complete.

What of the debt? It was assumed that some 40 per cent of the ¥37.1 trillion total could be taken over by the three major JR passenger companies, together with a Shinkansen holding company, and eventually be repaid through profits.[12] The remaining 60 per cent was to be assumed by the JNR Settlement Corporation, a holding company for the three profitable main island companies. It was estimated that 20 per cent of the debt could be raised from the sale of former JNR land surplus to requirements, a sum that was in fact exceeded during the bull land market of the late 1980s. The part of the sum which was not paid off was, in the last resort, to be assumed by the government. The situation is complicated and, by Japanese standards, acrimonious. Given the present economic downturn, the government wants more back from the companies, which in turn have suffered from the recession and resent continuing government interference.

Returning now to the growth of the Shinkansen. To the present-day observer the most singular feature of the Tokaido Shinkansen is the frequency of service. At the 1964 inauguration two trains per hour and sixty trains per day operated in both directions between Tokyo and Osaka. By March 1999 this had increased to eleven trains an hour and 285 trains per day. Of this daily total, fifty-one Nozomi trains stop at only the main stations, offering a travel time of 2 hr 30 min. to Osaka, compared with 4 hr at the opening, 147 Hikari trains stop at selected stations, whilst eighty-seven Kodama trains stop at all stations. Thus a truly remarkable intensity of service is now offered, and this growth has been mirrored to a lesser extent on the other Shinkansen lines. A major constraint has proved to be the handling of the huge number of passengers at Tokyo station, a situation which will be relieved by the opening of a new secondary station at nearby Shinagawa in October 2003.

The fourth generation of trains now operate on the Tokaido. Whilst the original Series 0 have recently been withdrawn, Series 100, 300, 500 and 700 trains have been introduced over the years, enabling both capacity and speed to be increased. The years since privatisation have seen rapid development of new stock as each company has sought to create an individual identity: JR Central on the Tokaido, JR West on the Sanyo, JR East on the Joetsu, Tohoku and Nagano Shinkansens. The many technical difficulties of increasing speed have been overcome by, *inter alia*, reducing the cross-sectional area of trains to decrease aerodynamic resistance and by reducing the weight of the vehicles to reduce axle loads and hence the dynamic forces on the track. A stage has been reached where the interior of the trains has assumed the size and feeling of an aeroplane, comfort levels in terms of space have been reduced and interior noise levels have increased.[13] Two particular developments are worthy of note. The JR West Series 500 is arguably the most elegantly profiled train in the world and is holder of the current world record

point-to-point timings, with sustained 300 km hr running over long stretches of the Sanyo route. In response to the increasing number of passengers using the Shinkansen for long-distance commuting into Tokyo, JR East have introduced the MAX, consisting of double-deck cars throughout its length, giving a seating capacity for 1,634 passengers.[14]

At the time of writing, some 2,300 km of dedicated Shinkansen track have been built. It is unlikely that the 7,200 km envisaged in the National Plan of 1969 will be completed in the foreseeable future, if ever, despite the enormous success, in particular, of the Tokaido line. We will therefore next examine some impacts of the Shinkansen on Japanese society and discuss changing circumstances which militate against the original ambitious plan.

The impact of the Shinkansen on Japanese society

The Shinkansen has many external effects on economic life. These range from the short-term spill-over effect of construction expenditure, through reduction in travel times and the introduction of private investment to the creation of employment due to the influx of new industries and enterprises in areas along lines and increased sightseeing and recreation demands. Between 1969 and 1999 the ridership on the Tokaido Shinkansen increased from 66 million to 130 million passengers per year, i.e. doubled. During this period Japan's GDP trebled. Many graphs have been produced showing the close linkage of ridership with GDP, and the government has always held the view that transport infrastructure is an enabler of economic growth.

Many of these effects have significant impacts on local economies; for example, the benefit due to reduced travel time might be estimated by converting the time saving over conventional transport into monetary values. If 85 per cent of the total passengers on the present Shinkansen lines are assumed to have shifted from conventional lines, the annual time saving calculated from the difference in timetables is approximately 400 million hours. By calculating the value of this time from GDP *per capita* data, its value may be approximately equated to ¥500 billion per year.

To illustrate the Shinkansen's effect on local economies, the case of Kakegawa, a medium-size city with a population of 72,000 some 230 km west of Tokyo and 50 km west of the prefectural city Shizuoka, should be considered.[15] When the Tokaido Shinkansen was built in 1964 the trains passed straight through Kakegawa and the city enjoyed none of the benefits. Because the distance between the nearest Shinkansen stations (Shikzuoka and Hamamatsu) was more than 70 km, the longest in Japan, and because Kakegawa was well served by local lines branching from the existing conventional Tokaido line at Kakegawa station, it was believed that stopping the Shinkansen at Kakegawa would revitalise not only the city but also the areas along the conventional and local lines. After funds had been raised from mainly local sources, a new Shinkansen station was built in 1988, with an almost immediate positive effect on the local economy: employment rose by 8 per cent in the subsequent four years, commercial production by 38 per

cent and industrial sales by 39 per cent. Five new hotels opened in the new station area to accommodate the ever-increasing number of tourists visiting nearby golf courses and other recreational facilities. The position of Kakegawa, approximately mid-way between Tokyo and Osaka, has made it a convenient site for national symposia and conferences, and, in the other directions, the citizens of Kakegawa can now experience the cultural life of Tokyo or Osaka because of the easier access afforded by the Shinkansen.

Many further examples could be given of the catalytic effect of the Shinkansen on local economies. Since the opening of the original line the number of stations serving smaller cities has increased, and service is possible because of the hugely increased frequency of operation of trains and the technique of allowing different patterns of stops along the route and the 'leapfrogging' of through trains past stationary trains at intermediate stations.

The environmental impact of the Shinkansen can broadly be subdivided into the (generally) beneficial energy effects and the effects on local areas, which are detrimental. By 1990 the transport share of Japan's oil consumption had reached about a quarter of Japan's total energy consumption. Compared with 1973, the industrial field had greatly reduced energy consumption owing to changes in industrial structure and energy-saving efforts, despite greater volume of output. Conversely, the energy used in transport had increased by a huge 170 per cent. Because transport energy is mainly derived from oil (98 per cent) and Japan now imports all its hydrocarbon energy, energy saving in transport is an urgent priority.

A broad comparison of energy use on a journey from Tokyo to Osaka, in terms of energy consumption *per capita*, shows the Shinkansen to be by far the most efficient mode,[16] largely because of the extremely high seat occupation rates achieved. If the Tokaido Shinkansen had not been constructed, an additional 360 million litres of oil would have been consumed by transport in 1985 – a figure which approximately corresponds to the oil consumption of 1.1 million families.

The consequence of energy use is, of course, the production of pollutant gases. Broad trends of use may be traced to emissions, with again considerable *per capita* advantage to the Shinkansen. The amount of carbon dioxide per unit transport volume produced directly by the Shikansen is only about 16 per cent that of a passenger car. The benefits of the 80 per cent share held by the Shinkansen of the transport volume between Tokyo and Osaka can thus be measured by, for example, an estimated 15,000 tons of CO_2 emissions in 1985. This corresponds to the annual amount of carbon dioxide emitted by industry in and around Tokyo. It has been estimated that, in order to replace the carrying capacity of the Shinkansen between Tokyo and Osaka, three Jumbo jets every five minutes would be needed, increasing domestic air travel by 50 per cent.[17] By road, forty-seat buses would need to be run every ten seconds, or, if passengers switched to private cars, 1,800 deaths and 10,000 serious injuries would result every year.

When the Shinkansen was first built, it was relatively easy to place the line without opposition from nearby residents or difficulties with planning

inquiries. The process of post-war rebuilding was more important than local sensibilities. However, the Shinkansen soon made its presence felt by noise and vibration, with the result that strict regulations have been established to limit these nuisances and counter-measures have had to be adopted by the operators to suppress the effects of the passing of high-speed trains. The acceptable maximum noise levels that have been set by legislation are 70 dB(A) for residential areas and 75 dB(A) in commercial zones. Because 56 per cent of the land near the Tokaido Shinkansen is classed as residential and 30 per cent commercial, the noise level is limited to less than 75 dB(A) for 86 per cent of the entire length of 513 km.

Noise increases rapidly as train speed increases, so that the speed increases of the Shinkansen have required continual technical developments in order to keep below the noise limits. Track structure and current collecting equipment have been improved, extensive lineside sound barriers have been developed and installed, vehicle weight has been reduced and rail and wheel tread cutting methods have been improved. All these measures increase costs. Moreover, at speeds over 300 km hr the noise energy increases proportionally to the sixth to eighth power of the speed, making noise suppressing developments much harder. (The power law dependence means, for example, that a 6 per cent increase in speed leads to a 140 per cent increase in noise.) A further problem has emerged with speed increases. As trains exit tunnels a micro-sonic boom can be heard over a wide area. Specially designed flared hoods have been fitted to tunnel exits to contain the problem. It is likely that the problems associated with noise generation are the ones which will limit further speed increases in the future.

Current status and future prospects of high-speed railways in Japan

The Shinkansen system is undoubtedly the world's leader in terms of volume, safety and punctuality. It has enabled trains to retain a much higher mode share of passenger traffic than in any other country. Switzerland, with 15 per cent rail/road passenger kilometres, leads in Europe. The ratio in Japan is a massive 57 per cent, despite the rise in automobile use in the last fifty years. The role of the Shinkansen in contributing to this figure is clearly shown in Figure 2, where passenger journeys of 400 km length are equally divided between road and the Shinkansen, which captures the lion's share before airlines take a larger share over 1,000 km.

There have been no derailments or collisions in over thirty-five years of service and hence no passenger fatalities or injuries from such causes. However, a major catastrophe was narrowly avoided on 17 January 1995 when the Kobe earthquake occurred some fourteen minutes before Shinkansen services started running. Damage to bridges and elevated sections took three months to repair. The importance of Automatic Train Control (ATC) was illustrated by an incident in February 2003. The driver of an express on the Sanyo Shinkansen fell asleep in his cab whilst the train was travelling at 275 km hr carrying 800 passengers, but the train stopped automatically, on

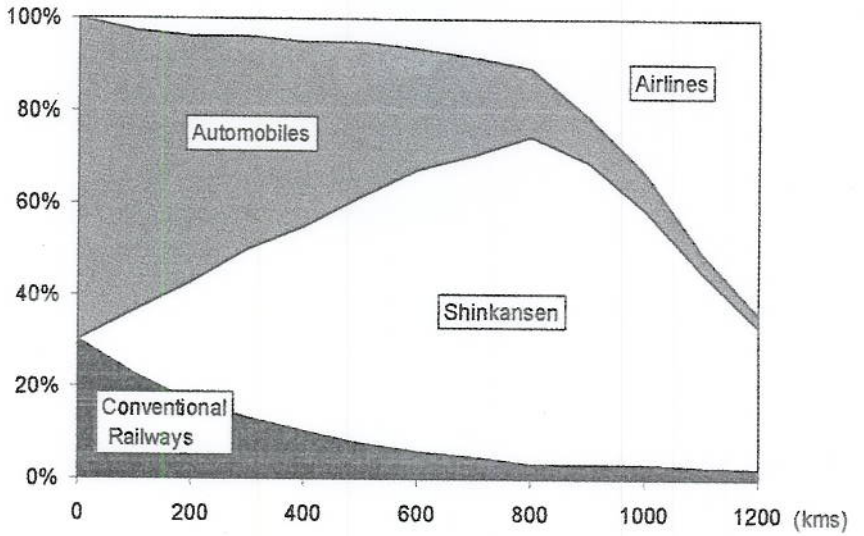

Figure 2 Share of the Shinkansen in various long-distance transport modes.
Source Modified, with permission, from H. Okada, 'Features and economic and social effects of the Shinkansen', *Japan Railway and Transport Review* 3 (1994), pp. 9–16, at p. 11

schedule, at Okayama station. The punctuality is legendary. In 1998, out of a total of more than 200,000 train departures on the Tokaido Shinkansen, 96.1 per cent arrived exactly on time at Tokyo or Osaka and 99.1 per cent arrived within nine minutes of schedule.[18]

Despite this superb performance, future expansion of the system is likely to be limited. It must be remembered that the Tokaido Shinkansen serves an area which creates the largest and most stable demand in the world. The greater Tokaido area is 17 per cent of Japan's land area but houses 40 per cent of the population and produces 49 per cent of GDP. The other Shinkansen lines do not have this benefit of concentration. Work is in hand in the JR East region to extend the Tohoku line from Morioka to Aomori and the Nagano line to Joetsu. At the opposite end of Japan, the Sanyo line is being extended to form the Kyushu Shinkansen from Hakata in the north to Kagoshima in the south. It is difficult to see significant expansion beyond these schemes in the future.[19] In essence the obvious and profitable routes have been built and low densities of traffic at the extremities are likely to prove unfavourable. Environmental opposition mainly concerned with noise and vibration is also gathering strength, and is likely to prevent significant speed-up of existing lines. Furthermore, the millstone of debt from the former JNR will remain a stumbling block. As distances from Tokyo grow, so time competition from the airlines becomes more difficult for the train to match, and price competition on the existing routes is becoming more severe as the internal airlines are liberalised. Travel conditions in the major cities is becoming yet more difficult despite extensive networks of public transport. The time taken to travel to and from the Shinkansen station is becoming an ever-increasing and significant proportion

of door-to-door journey times. Therefore national priority is likely to shift to these urban transport problems.

However, on the first and earliest of the Shinkansen routes, capacity limits are being reached – not only in line capacity for trains, but also in station capacity for handling large numbers of people. The new station at Shinagawa in Tokyo will allow an increase on the Tokaido line to fifteen trains per hour. Beyond that, further increases will require drastic measures. Just as the Shinkansen was born out of the inability of the old conventional Tokaido line to absorb further expansion, so history is repeating itself as a new type of train is being tested on a trial section of a proposed new line connecting Tokyo and Osaka, the Chuo Shinkansen. The projected route lies inland, generally to the north of the Tokaido, roughly following another ancient route of Japan, the Nakasendo. Because of the very mountainous terrain and the need for very shallow radius curves, most of the route will be in tunnels, with consequent heavy civil engineering costs. The 18.4 km test section has been built in Yamanashi, where superconducting magnetically levitated (Maglev) trains are being tested. Technical progress has been another spectacular example of Japanese prowess. Passing tests have achieved a relative train speed of 1,003 km per hour and on 14 April 1999 a world speed record for a manned train of 552 km hr was reached during running tests. The huge construction and equipment tests of this new technology will undoubtedly play a significant part in some difficult decisions soon to be made on whether the project will go ahead and on whether the motive power will be the new Maglev or a traditional steel-wheel-on-steel-rail Shinkansen.

The Shinkansen as a catalyst

At the beginning of this article it was stated that the birth of the Shinkansen was viewed with considerable scepticism in the West. Some forty years on, Japan, largely through the success of the Shinkansen, is acknowledged as the world leader in railway technology and operation. Furthermore, the obvious advantages of the Shinkansen in both speed and capacity have stimulated the construction of dedicated high-speed lines in many other countries. In Europe, the French 410 km Paris to Lyon line, opened between 1981 and 1983, was the beginning of the high-speed train revolution in the West.[20] Germany inaugurated its ICE services in 1991 and other countries quickly followed. By the end of 2002 a total of 3,260 km of new high-speed line was in operation, comprising 1,520 km in France, 471 in Spain, 246 in Italy, 142 in Belgium, the 52 km Channel tunnel linking France and Britain and 15 km in Denmark. A total of 6,000 km are planned for 2010, extending to 10,000 km by 2020. By then Austria, the Netherlands, Finland and Switzerland will have joined the 'high-speed club'.

Spain is particularly noteworthy. The new line from Madrid to Seville, opened in 1992, cut the journey time from six hours to two hours fifteen minutes. The line from Madrid to Barcelona (620 km long) will open between

2002 and 2004, allowing 350 km hr running. By 2007 the Spanish government plans to have 7,000 km of new or upgraded lines.

In general, journey times have been halved and the new lines have captured traffic from the airlines (rail's share is over 75 per cent for journeys up to two and a half hours) and roads, whilst generating new traffic. Decades of railway decline have been reversed, with annual passenger growths averaging 8 per cent on the new railways. On railways as a whole in Europe, on journeys over 80 km, a 60 per cent growth of passenger kilometres is expected between 2000 and 2020.[21] Elsewhere, Taiwan, South Korea and China will have completed major routes, and interest has been stimulated even in the United States. On the occasion of the thirtieth anniversary of the Tokaido Shinkansen, Hideo Shima, then aged ninety-three, the 'father' of the Shinkansen and doyen of the Japanese railway industry, was interviewed for a special issue of *JR Tokai*.[22] He commented:

> There seems to be a kind of competition around the world today to achieve ever higher railway speed. Personally, I think they are making a mistake targeting their sights always on faster and faster speed alone. Instead of speed, other countries should try instead to emulate the Shinkansen's remarkable frequency of train headway.
>
> Frequency, I believe, is far more vital than higher speed. For unless you boost operation frequency, you can't reduce passenger fares and attract more customers.
>
> From now on, the first priorities of train transport must be low energy, safety and comfort.

Notes

1 Literal translation: 'New Main Line'. All translations by the author.
2 Cf. R. J. Bowring and P. Kornicki (eds), *The Cambridge Encyclopaedia of Japan* (Cambridge, 1993), p. 363. This is also an excellent and comprehensive reference to many aspects of Japan's development.
3 Although there are many scattered references to the history of railways in Japan, few books have appeared in the West on this topic. From 1994 to 1997 the *Japan Railway and Transport Review* carried a series on the history of Japan's railways. These were published in an extended form as E. Aoki *et al.* (eds), *A History of Japanese Railways, 1872–1998* (Tokyo, 2000). Of particular interest in respect of the Shinkansen is Y. Wakuda, 'Railway modernisation and Shinkansen', *Japan Railway and Transport Review* 9 (1997), pp. 60–3. A separate history and extensive technical and operational description of the Shinkansen are given in P. Semmens, *High Speed Japan: Shinkansen – the world's busiest high-speed railway* (Sheffield, 1997, second edition 2000).
4 R. A. Smith, 'The first railway in Japan: British connections, Edmund Morel and a romantic story', *Bulletin, Journal of the Japan Railway Society*, 24 (1997), pp. 20–1.
5 Many aspects of the immediate post-war phase of Japan's history are discussed in J. Dower, *Embracing Defeat: Japan in the aftermath of World War II* (1999).
6 Cf., for example, H. Odagiri and A. Goto, 'The Japanese system of innovation: past, present and future', in R. Nelson (ed.), *National Innovation Systems: a comparative analysis* (New York and Oxford, 1993), pp. 76–114.
7 Cf. Semmens, *High Speed Japan*, p. 7. This was the hope that the old style of thinking would be left behind together with the old railway.
8 Cf. B. Hosokawa, *Old Man Thunder. Father of the Bullet Train* (Denver CO, 1997).
9 At a recent meeting with senior staff of the Railway Division of the Japanese Ministry of Transport, British colleagues asked how safety expenditure was evaluated on cost–benefit

lines. There was some confusion among the Japanese delegates, who finally answered, 'We propose what is necessary, then work out how it should be paid for.'

10 Cf. Aoki, *History of Japanese Railways*, p. 114.

11 This subsidiary business is an example of recent diversification by JR East after 'privatisation' in 1987: see later.

12 J. A. Doherty, 'The railway policy debate in Japan and its domination by old debt', *Journal of Transport Economics and Policy* 33 (1999), pp. 95–110.

13 For example, in the author's view, the level of comfort attained on the upper decks of the Series 100 double-deck cars of 1985 has been diminished in subsequent designs.

14 'MAX' stands for 'Multi-Amenity Express'.

15 The effects of the Shinkansen on the economic growth of Kakegawa and the environmental effects are discussed in more detail in H. Okada, 'Features and economic and social effects of the Shinkansen', *Japan Railway and Transport Review* 3 (1994), pp. 9–16. (This edition carried several special features marking thirty years of high-speed railways.)

16 Shinkansen–automobile–aeroplane in the ratios 1 : 4.6 : 5.2.

17 Cf. S. Yamanouchi, *If there were no Shinkansen*, East Japan Railway Company (Tokyo, 2000).

18 By contrast, in Britain a train is not counted as late if it arrives within ten minutes of the timetable.

19 An exceptionally frank analysis of Japan's railway policies in the nineteenth century and an argument for curtailing further expansion of the Shinkansen (and highway) systems can be found in R. Kakumoto, 'Sensible politics and transport theories? Japan's National Railways in the nineteenth century', *Japan Railway and Transport Review* 22 (1999), pp. 23–33.

20 Cf. anon., *High Speed Trains in Europe* and *High Speed around the World*, Union internationale des chemins de fer (UIC) (Paris, 2002).

21 With the exception of the Channel tunnel link to London, there is every indication that the high-speed rail revolution will bypass Britain, the birthplace of railways. In order to stimulate interest, the author was instrumental in arranging the generous donation by J. R. West of a gift of an original Series 0 leading cab to the National Railway Museum in York, where it has been on display since summer 2001. He was highly gratified when, on asking a party of schoolchildren waiting to enter the museum what they hoped to see, the chorus came back, 'The Bullet Train.'

22 H. Shima, 'Transport capacity before speed: Tokaido Shinkansen', *JR Tokai*, thirtieth anniversary special issue, 'Technical report' (Tokyo, 1994). After being snubbed and excluded from the Shinkansen opening ceremony in 1964, Shima was gradually rehabilitated into the highest levels of Japanese technological development. In 1969 he became first chairman of the National Space Development Agency. Belatedly he was honoured as a 'Person of Cultural Merit' by the Japanese government, and died, a much revered figure, on 19 March 1998.

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