Features and Economic and Social Effects of The Shinkansen

Hiroshi Okada

The railway is deeply rooted in land and society. Therefore, it is developed to match the nature and cultural climate of a nation. This paper describes the features of Japan and how they characterise her shinkansen inter-city transport system. It also describes the effects of the shinkansen on the railway business and society.

1. Features of Japan

1.1 Geographical conditions and location of cities

Japan has a large population (120 million) in a comparatively-small land area (377,000 square kilometers). The centre of Japan is dominated by steep mountains, and most of the large cities and industrial areas have developed along the coastal plain (Figure 1). The ratio of habitable land to total land area is only 20%, resulting in a high population density on habitable land.

The Japanese population is concentrated in cities, particularly in three metropolitan areas. Approximately 30 million, 16 million and 8.5 million people live within 50 km of central Tokyo, Osaka and Nagoya, respectively.

1.2 Young geology with frequent earthquakes

In general, the surface of the habitable plains is geologically weak and covered mostly by thick alluvium. By contrast, orogenic movement is active in mountainous regions, forming quite complicated strata. Since the Japanese archipelago is located on the Pan-Pacific Seismic Zone, strong earthquakes are very frequent.

1.3 High annual precipitation

Japan has high annual precipitation; in the rainy season from June to July, south Honshu and southern areas have a great deal of rain. On the other hand, in winter, Hokkaido and the districts along the Sea of Japan have very high snowfall. In summer and autumn, Japan is often hit directly by typhoons accompanied by strong rain and high wind.

The annual precipitation of Tokyo is 1405 mm (average from 1961 to 1990) compared with London (753 mm), Paris (648 mm), Berlin (584 mm), Moscow (692 mm), New York (1069 mm), Beijing (578 mm).

2. Railway Development Matching National Features

This chapter explains how the features described above characterise Japanese railways, as well as the techniques developed to adapt to them.

2.1 Features of Japanese transportation market

Most major cities in Japan are on the linear coastal plain. In addition, Japan is a long slender archipelago and there are no true inland areas. Furthermore, Japan is poor in natural resources. These factors have greatly influenced the passenger and freight railway transportation systems as well as their technical development.

1) Low share of freight railway transportation

It is no exaggeration to say that freight railway transport dominates railway transportation worldwide. However, because Japan is surrounded by sea, because most large cities and industrial areas are on the coastal plains, and because the inland areas do not yield great mineral resources, there is almost no demand for mass long-distance transportation, which is the best field for freight railway.

As a result, except during the war when domestic coal dominated energy resources, the Japanese railway has never had a large share of the freight transportation market. Nowadays, trucks dominate land freight transport, and coastal shipping continues to have a very high share.

However, today, freight railway can fully demonstrate its advantages of punctuality and high speed by container or piggyback transportation of high-value, light goods. Thanks to technological developments in both hardware and software, Japanese freight railway transportation is showing remarkable growth.

2) Active passenger railway transportation

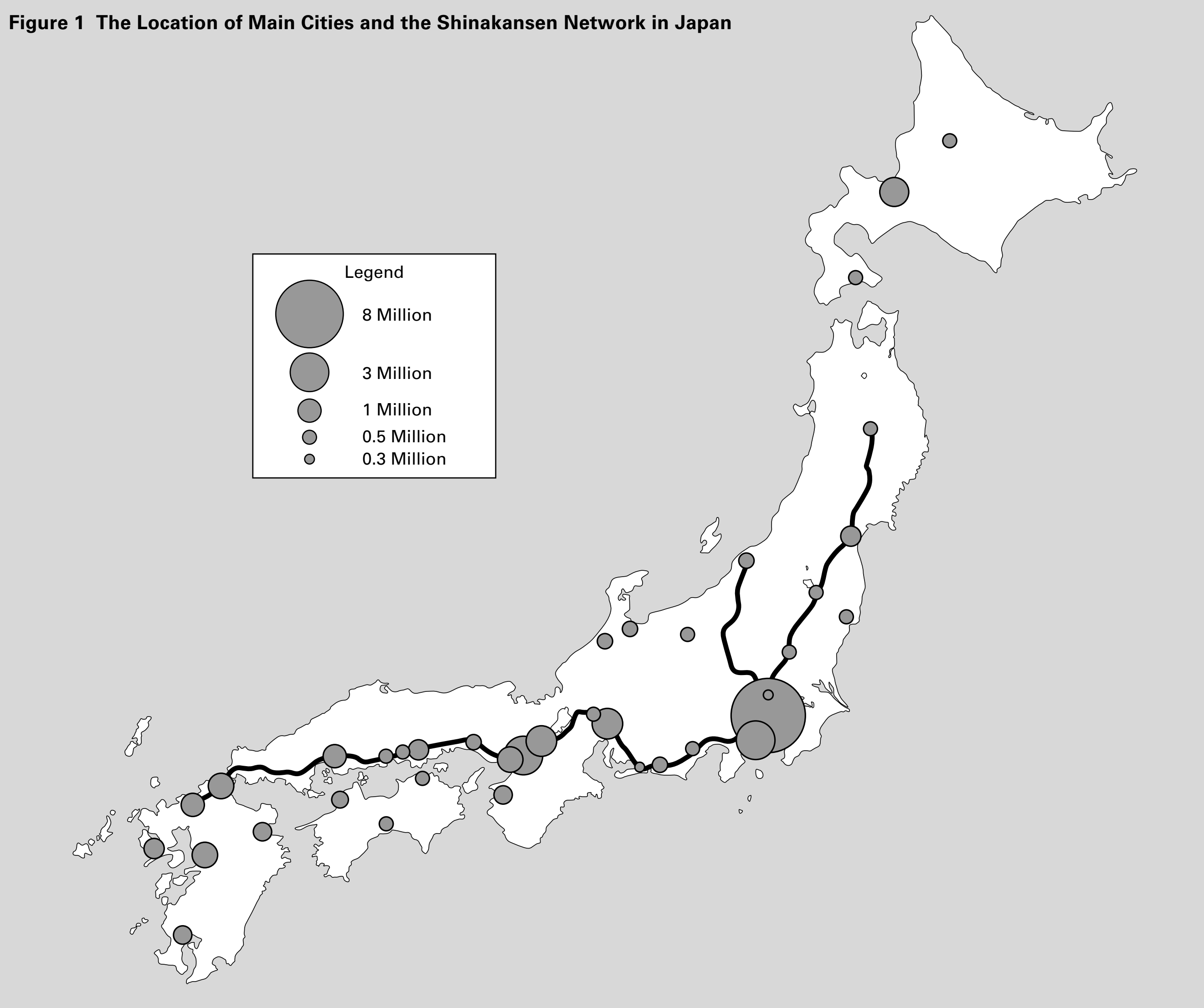
Since most large cities are located almost linearly along the coastal plain and the population density is very high, these areas are perfect for passenger railway transportation. Therefore, despite the remarkable development of airlines and express highways, passenger railway transportation holds about a 30% share of the increasing transportation volume year after year.

Railways are dominated by inter-city passenger transportation centered on the shinkansen and by urban commuting in metropolitan areas such as Tokyo and Osaka.

Table 1 Population Density (per square km habitable land)

Japan	Former West Germany	France	England	USA
1500	360	160	260	50

Figure 1 The Location of Main Cities and the Shinakansen Network in Japan



2.2 Technical features of shinkansen

1) High frequency, short station-station distance

The shinkansen is characterised by high frequency and short station-station distance; these characters are attributable to the high population density and the location of cities along the lines.

The Tokaido Shinkansen is a typical example. Its daily average transport density (annual passenger km/route km/365) in 1992 reached 220,000 passengers. In rush hours, shinkansen trains depart Tokyo Station at intervals of 6 minutes or less, carrying 23,000 passengers per hour one way. No other rapid-transit railway has achieved such high-frequency as far as inter-city transportation is concerned.

In addition, many core cities are located close to each other on the route, resulting in short station-station distance (approximately 35 km) compared with European rapid-transit railways.

When station-station distance is short, schedule speed drops if all trains stop at each station, lowering the significance of a rapid-transit railway. To avoid this, various trains are operated to meet the diversified needs of passengers; the *Nozomi* stops at almost no intermediate stations, the *Hikari* stops only at major intermediate stations and the *Kodama* stops at each station (Figure 5).

2) Feeder service network

It is very important for high-speed intercity railways to be served by well-developed feeder networks, because passengers must be able to access the high-speed rail station easily by other means of transport, such as suburban railway, subway, bus, taxi, and bicycle at the trip origin and destination. In general, because Japanese railways were built before or during the development of modern cities and also because railways were the only means of modern transport for a long time, the major railway stations are located at the hearts of the cities. In other words, urban development of major cities took place from the major railway stations.

As a result, various city transport systems converge on the main railway

Figure 2 Trend in Modal Split of Various Means of Freight Transportation (Percentage in ton-km for goods traffic)

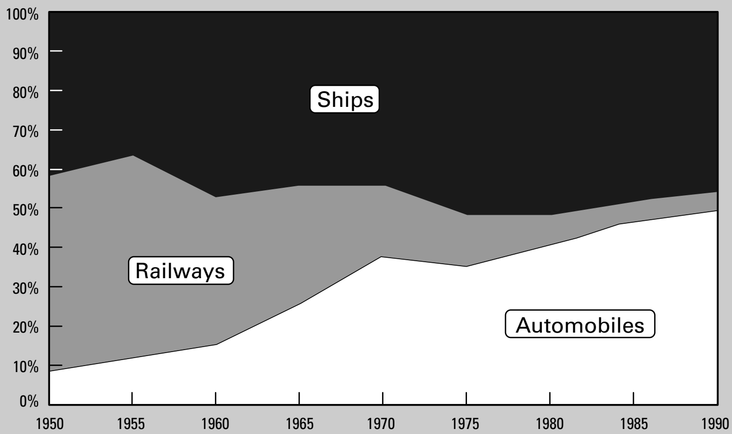


Figure 3 Trend in Modal Split of Various Means of Passenger Transportation (percentage in number-km for passenger traffic)

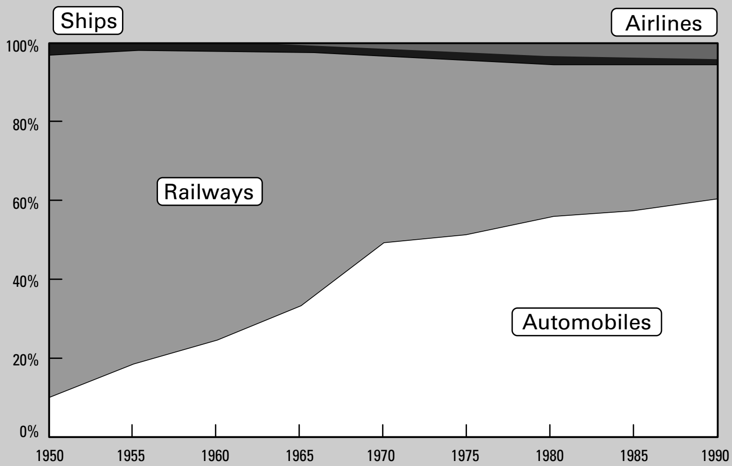
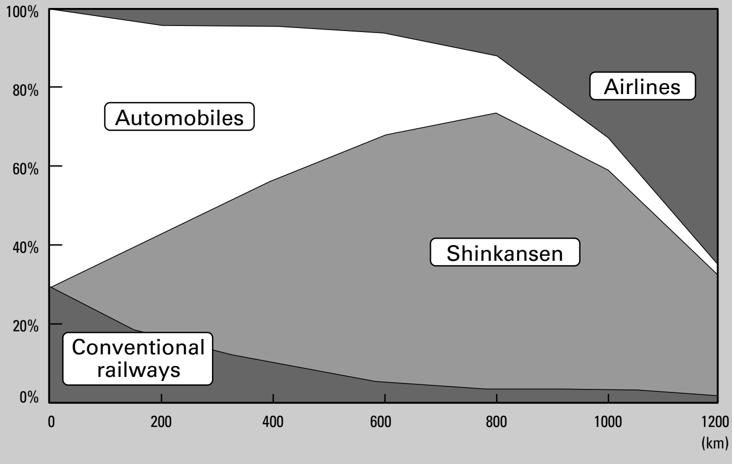


Figure 4 Share of Shinkansen in Various Long-Distance Transportation Modes



stations, making it easy to access the station from every part of the city. This is why shinkansen stations were planned and constructed in existing stations.

3) Adoption of multiple unit system

To achive the above-mentioned high-frequency, high-speed railway transport with short station interval, the multiple unit system, or electric rail cars, were adopted, although this system had hardly never been used before in long-distance railways worldwide.

Until 1950 in Japan, electric railcars were used only for short-distance urban or suburban railways, while long-distance, high-speed express trains were hauled by locomotive. In 1950, electric railcars with excellent acceleration were used for distances up to 120 km or longer to increase the almost saturated capacity on the conventional Tokaido Line. Subsequent technological development led to introduction of the super-express electric railcar to connect Tokyo and Osaka more rapidly. This electric railcar became the model for the shinkansen.

An electric railcar with many driven wheels has high acceleration/deceleration and the transport capacity can be increased easily, making it suitable for high-frequency, short station-station distance transportation.

For super-high speed railways, this type of train has smooth and efficient braking performance because each motor works as an electric brake solving the problem of disc brakes being applied at very high speeds.

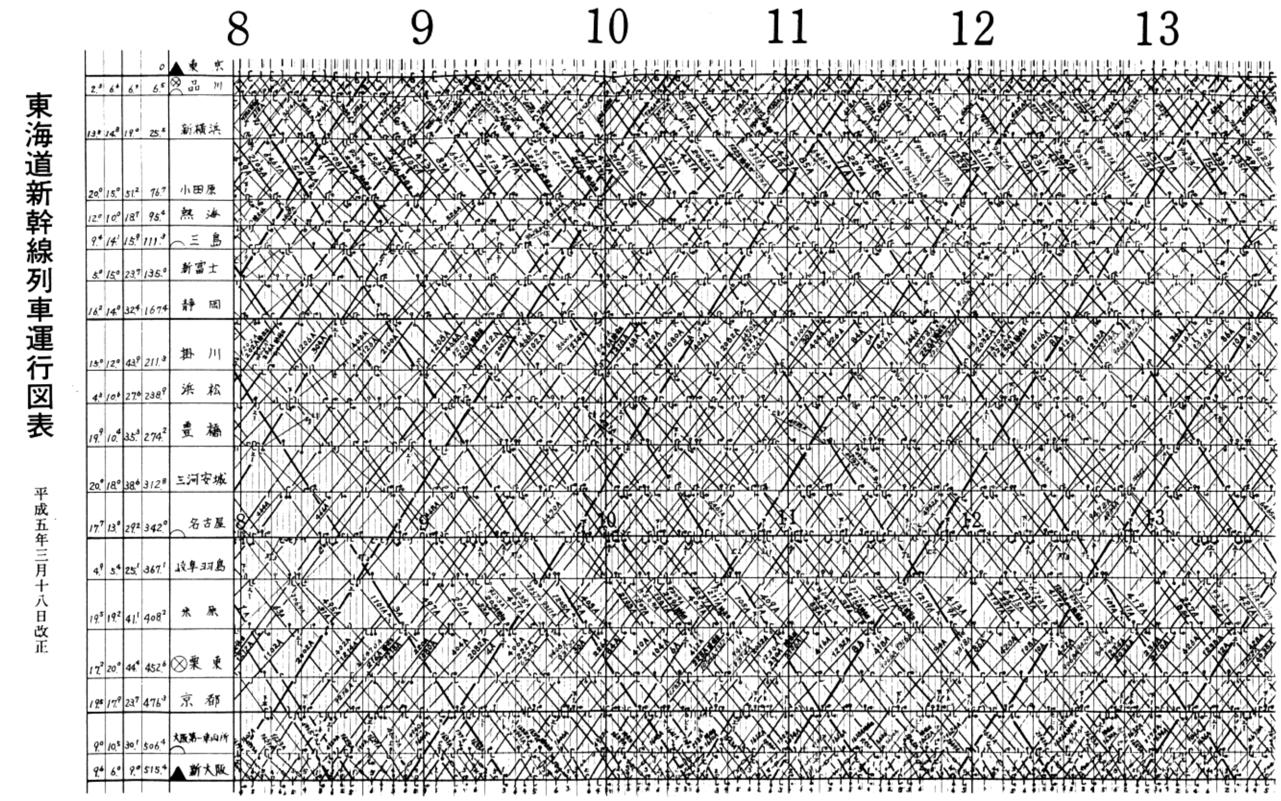
The distributed power system has another advantage over the centralised power system; the maximum axle load can be reduced for the same train weight, which is very advantageous on weak ground.

4) Strict environmental standards

The high population density on habitable land means that the population density along shinkansen lines is also high. When you ride a shinkansen train for the first time, you are surprised by the rows of houses continuing without break except at tunnel sections.

Therefore, strict regulations were established for noise and vibration for the

Figure 5 Train Diagram of Tokaido Shinkansen from Tokyo (Top) to Shin-Osaka (Bottom) Stations



shinkansen.

Residential areas comprise 56% of the 513 km of the Tokaido Shinkansen connecting Tokyo with Osaka; commercial areas comprise 30%. In other words, the noise level is limited below 75 dB (A) over 86% of the total length.

The noise emitted by a train comes from various sources, such as the wheels rolling on the rail, and the pantograph sliding on the trolley line. Noise increases rapidly as train speed increases. Shinkansen speed increases have been achieved by continuous technological developments to keep below the noise limit: track structure and current-collecting equipment have been improved, interference-type sound barriers have been developed, car weight has been reduced, and rail and wheel tread cutting methods have been developed.

However, at speeds over 300 km/h, the noise energy increases in proportion to the 6th to 8th power of the speed, making technological development to reduce noise much harder.

It is no exaggeration to say that the greatest problem hindering shinkansen speed increase is noise emission.

5) Why shinkansen requires high construction cost

Compared with rapid-transit railways in Europe, the construction cost per kilometer for the shinkansen is very high. Why?

In general, rapid-transit railways require a large investment in electrical-related construction, including signalling and safety systems, power systems and communication systems. However, the civil-engineering costs, such as banking, bridges and tunnels, still dominate taking approximately 70%.

The shinkansen requires higher civil-engineering costs than European rapid-transit railways for the following reasons.

a. Too many tunnels

Because high mountains are common in Japan, the ratio of tunnel sections to the total length of the shinkansen tends to be high. The total tunnel length of the existing four shinkansen lines is 30.8% of the total length of the lines.

b. Few sections can use economic banking

Frequent earthquakes, heavy rain and deep weak ground on the plains do not suit the economic banking method and few sections can use it. Elevated track (including site acquisition cost)

Table 2 Noise Level Limit for Shinkansen

Land type along line	Limit noise level dB (A)
Residential area	70 max.
Commercial area	75 max.

costs about four times that of banking.

c. High environmental costs

To meet the strict environmental standards, cost for sound barriers and ballast mats, etc., tend to be high.

d. Short station-station distance

The distance from station to station is too short (30 to 40 km) to achieve rational transportation compared with European rapid-transit railways. Station construction requires higher costs, raising the total construction cost.

In comparing the vehicle cost per seat, Japanese shinkansen is cheaper than rapid-transit railways in other countries, and the maintenance cost of VVVF-controlled cars is very low.

3. Effects of Shinkansen on Railway Business

3.1 High revenue

1) Strong competitive power—increased transport volume

The shinkansen provides fast, safe and punctual transportation with good connections to auxiliary transport. Consequently, the shinkansen is very competitive against other means of transport, such as cars and airlines.

In addition, the shinkansen has excellent ride comfort, interiors and onboard facilities. Thanks to these advantages, the shinkansen attracts many passengers and takes a large share of inter-city passenger transport.

2) High fares

Due to the high-quality service, including short arrival time, and strong competitive power, shinkansen fares can be set at comparatively-high levels.

3) Additional income from related business

Since passengers visit shinkansen stations for various purposes, such as business trips and sightseeing, related businesses such as department stores and hotels can be run using the station site to get additional income. For example, of 18 stations on the Tohoku Shinkansen connecting Tokyo with Morioka, seven stations have large-scale department stores and other related businesses. Three of these seven stations have large-scale urban hotels with large conference rooms.

3.2 Relatively-small increase in expenses

We tend to think that the costs of a railway increase as transport volume and speed increase. However, in reality, many factors are really not related to transport volume and speed. These factors cannot be neglected. For example, the construction and maintenance costs of elevated track, banking and tunnels hardly change with transport volume and speed. In addition, despite high unit cost, high-speed rolling stock has a high operating efficiency due to high speed, resulting in a smaller number of rolling stock required for the same transport volume.

Table 4 shows how the main expenses change with speed and transport volume.

3.3 High profitability

What about the economy of the shinkansen from the railway business viewpoint, namely, the relationship between the income and expenses per unit transport volume?

As explained above, the income per unit transport volume (fare including express charges) of the shinkansen is large. And additional income from related enterprises can also be expected.

As far as the expenses are concerned, they consist of various factors. Although some increase with speed increase, there are other factors that do not significantly increase with transport volume (for example, construction cost of bridges or tunnels). In this context, the unit cost of very high-speed railways can be expected to be less than that of conventional line thanks to the large traffic volume induced by high-speed service.

Therefore, for lines with high demand, the shinkansen is more profitable than conventional inter-city railways.

3.4 Concrete effects of shinkansen on railway business

When the Japanese National Railways (JNR) was divided and privatised in March 1987, the shinkansen operated on four sections (Tokaido, Sanyo, Tohoku and Joetsu), and the total service length was 1835 km. The shinkansen network had run well even in the JNR era. At the division and privatisation, the government, considering the high profitability, leased the shinkansen facilities at the replacement price (¥ 8.5 trillion) or 1.5 times the book value (¥ 5.7 trillion) to the passenger railway companies. The difference (¥ 2.8 trillion) helped reduce the huge long-term debt left by JNR.

Because the shinkansen business results continued to be favorable after the privatisation, the JRs decided to purchase the shinkansen facilities for a total ¥ 9.2 trillion or approximately ¥ 700 billion more than the appraised value at the JNR division and privatisation. The difference was appropriated as part of the Railway Reinforcement Funds for constructing new shinkansen lines, increasing the speed of conventional lines, and reinforcing the commuter transport capacity.

The Tokaido Shinkansen is only 25% of the total service kilometers of JR Central but dominates the total income (85%). Thus, the Tokaido Shinkansen is the backbone of JR Central.

These examples clearly show how helpful the shinkansen is in railway business.

4. Effects of Shinkansen on External Economy

The shinkansen has diverse effects on the external economy including the spillover effect of construction expendi-

Table 3 Comparison of Fares between Tokyo and Osaka

Category	Fare yen	Remarks
Shinkansen	13,480	Unreserved ordinary seat
Conventional line	10,080	Ordinary seat express car
Airline	14,600	
Highway	9,800	Toll for 1 passenger car

Table 4 Change in Expenses with Speed and Transport Volume

Item	Change with speed	Change with transport volume
Construction investment	Almost no change (bridge, tunnel, etc.)	Almost no change (bridge, tunnel, etc.)
Structure maintenance cost	Almost no change (bridge, tunnel, etc.)	Almost change (bridge, tunnel, etc.)
Track maintenance cost	Increase	Increase
Trolley line maintenance cost	Increase	Increase
Rolling stock investment	Car unit cost increases, but the number of cars decreases due to increased operation efficiency.	Increase
Rolling stock maintenance cost	Small increase (partly decreased by increased operation efficiency)	Increase
Power cost	Increase	Increase
Crew cost	Decrease (due to increased productivity from speed increase)	Increase

ture during construction (short-term), reduction in travel times, introduction of private investment and creation of employment due to influx of new industries and enterprises in areas along lines, and increased sightseeing and recreation demands. Thus, the shinkansen contributes to the development of local economies. Studies are in progress to quantify these effects. The following sections give some concrete examples.

4.1 Benefits due reduced travel time

The method used most often to quantify the effect of rapid transport on the social economy is to convert the time saving compared with conventional transport into money.

If 85% of the total passengers on the present four shinkansen lines shifted from conventional lines, the annual time saving calculated from the difference in schedule times between the shinkansen and conventional lines is approximately 400 million hours. By calculating the value of the time per hour from the GDP per capita, the value of the time saving is approximately ¥ 500 billion per year.

4.2 Example of urban redevelopment near shinkansen station

1) Redevelopment of Kakegawa City on Tokaido Shinkansen

Kakegawa is a medium-size city on the Tokaido Shinkansen with a population of 72,000. It is in western Shizuoka, about 230 km west of Tokyo, and approximately 50 km west of Shizuoka, the prefectural seat.

When the Tokaido Shinkansen was opened in 1964, trains passed behind Kakegawa Station on the conventional Tokaido Line, and the city enjoyed no benefit.

Because the distance between the adjacent shinkansen stations (Shizuoka Station and Hamamatsu Station) was 71.5 km, the longest in Japan, and because local lines branch from the conventional Tokaido Line at Kakegawa Station, the local people believed that stopping shinkansen trains at Kakegawa Station would surely revitalise both Kakegawa City and all the areas along the conventional Tokaido Line and local lines. Consequently, a new station was built in 1988 with the total construction cost paid by the prefecture, Kakegawa City (funds mostly raised by the citizens) and adjacent cities, towns and villages. The new shinkansen station has had a great effect on the economy, lifestyle and culture of Kakegawa City, as shown below.

A. Increase in employment and industrial shipments

Table 5 shows the change in employment and production in industrial fields, while Table 6 shows the change in employment and sales in commercial fields. After the station opened, production and sales show a remarkable increase.

B. Increase in number of tourists and conferences

Two city hotels and three business hotels have already opened around the station to accommodate the ever-increasing number of tourists visiting nearby golf courses and other recreational facilities. Another advantage of Kakegawa City is its mid-way location between Tokyo and Osaka. This makes it a convenient site for national symposiums and conferences which are greatly changing the outlook of the citizens.

C. Culture

Before the opening of the shinkansen station, the citizens of Kakegawa City had hardly any chance to experience the culture of Tokyo, Kyoto, Osaka and other metropolises. Now, the shinkansen offers them easy access to concerts, exhibitions, theaters, etc., enabling them to lead fuller lives.

2) Change around station due to opening of shinkansen

Some examples of the change around a station due to the opening of shinkansen are shown below.

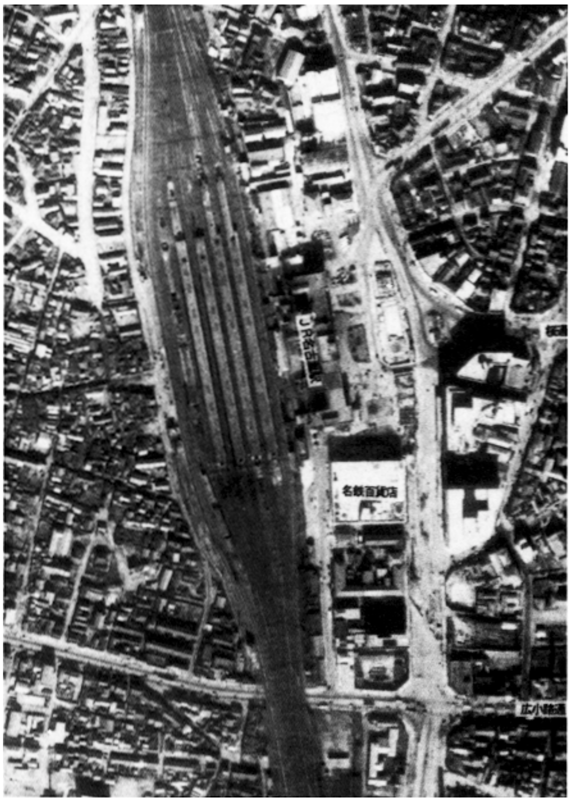


Photo 1 Nagoya Station Before Construction of Shinkansen Station

• • • and Today

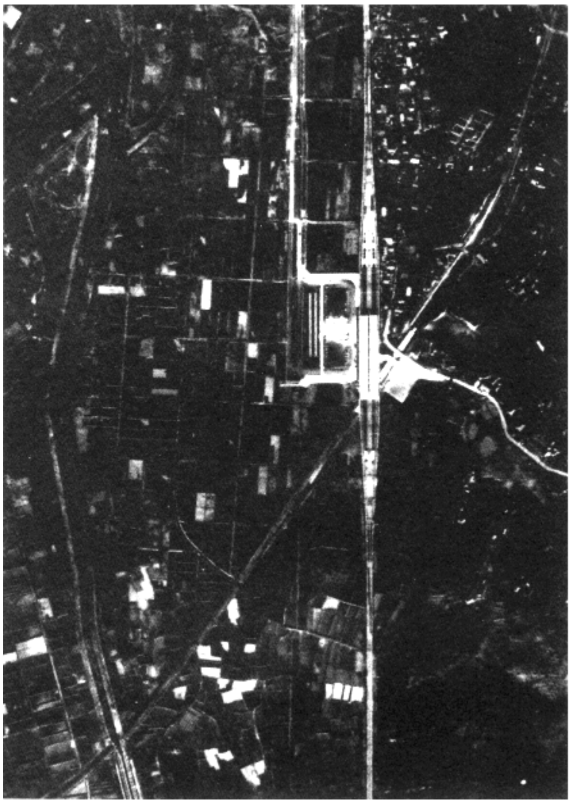


Photo 2 Shin-Yokohama Shinkansen Station Under Construction

• • • and Today

(from Author's collection)

A. Shinkansen station constructed in existing station on conventional line (Photo 1 Nagoya Station)

The shinkansen station was constructed at the back of the existing Tokaido Line station.

B. New shinkansen station (Photo 2 Shin-Yokohama Station)

The shinkansen station was constructed on a branch line about 8 km from Yokohama Station on the conventional Tokaido Line.

4.3 Energy efficiency

Table 7 shows the trend in energy consumption categorized by three fields: industrial, non-industrial and transportation. In 1990, the transportation share formed about 25% of the total energy consumption of Japan. Compared with 1973, the industrial field has greatly reduced energy consumption due to changes in the industrial structure and energy-saving efforts, despite great increases in shipments. On the other hand, the transportation field has greatly increased energy consumption by about 170%.

Transportation depends largely (about 98%) on oil. (Japan average: 61%). Therefore, energy saving in transportation is very urgent.

Table 8 compares travel from Tokyo to Osaka by shinkansen, airline and passenger car in terms of energy consumption per capita. The shinkansen is much more energy efficient.

If the Tokaido Shinkansen had not been constructed, an additional 360 million liters of oil would have been consumed in 1985 by transport. This corresponds to the total oil consumption of 1.08 million families.

4.4 Air pollution and shinkansen

Compared with other means of transport, the shinkansen hardly emits any CO_2, NOx and other harmful gases. Although the shinkansen has an 80% share of the total transportation volume between Tokyo and Osaka, the amount of CO_2 per unit transport volume produced directly by the shinkansen is only about 16% that of a passenger car (Table 9).

If the Tokaido Shinkansen had not been constructed, about 15,000 tons more CO_2 would have been emitted in 1985. This corresponds to the annual amount of CO_2 emitted by industry in and around Tokyo.

Table 5 Trend in Employment and Sales in Commercial Fields (Kakegawa City)

Year	1985	1986	1987	1988	1989	1990	1991	1992
Employment	96.0	98.6	96.8	100.0	101.5	103.5	103.2	108.1
Production	100.1	96.0	98.1	100.0	105.2	110.4	109.5	137.6

Table 6 Trend in Employment and Production in Industrial Fields (Kakegawa City)

Year	1985	1988	1991
Employment	88.8	100.0	106.9
Sales	85.4	100.0	139.2

Table 7 Oil Consumption (million kiloliter)

	1973		1990	
Industrial	187	65%	183	53%
Non-industrial	52	18%	85	24%
Transportation	47	16%	80	23%
Total	286	100%	348	100%

Table 8 Comparison of Energy Consumption per 100 Million Passenger-Kilometers (*)

	Shinkansen	Automobile	Aeroplane
Energy consumption (kcal/100 million passenger-km)	136	631	714
Ratio	100	464	525

*Akiyama, *et al.*, "Re-evaluation of The Shinkansen", JREA 1990, Vol. 33, No.2

Table 9 Emission of CO_2 Per Capita by Transportation between Tokyo and Osaka (*)

	Shinkansen	Automobile	Aeroplane
Index	100	547	631

*"1993 White Paper on Transport", the Ministry of Transport

Conclusion

The shinkansen has been greatly influenced by Japanese geography and society. It has also had a great effect on Japan's business, economy, society, environment and culture.

These effects result from the superiority of the shinkansen over other means of transportation in terms of speed, safety, punctuality, etc. ■

Hiroshi Okada

Dr Okada was born in 1930 and studied civil engineering at the University of Tokyo. He joined JNR in 1953 and worked on various projects including construction of the shinkansen network. From 1979 to 1980, he visited in Ohio, USA, giving advice on high-speed rail development. He became Director General of JNR's Civil Engineering Department in 1982, Board Member in 1983 and Vice President/Engineering in 1986. He was Vice President and President of the Japan Railway Construction Public Corporation from 1987 to 1992, and he currently serves as President of Japan Railway Technical Service (JARTS), representing Japanese railway engineers to the rest of the world.