RE-EVALUATION OF THE SHINKANSEN

FROM THE STANDPOINT OF ENERGY CONSUMPTION, ENVIRONMENTAL PROTECTION AND PRESERVATION OF HUMAN LIFE

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1. INTRODUCTION

There are various aspects, for example, to effects of transportation projects. The Japanese government must evaluate a particular project from the standpoint of national economic growth, while at the same time considering the balance of development throughout the country. Local governments, which evaluate projects with their locale in mind, make every effort to secure transportation projects for their area. While residents in these areas certainly value modern transportation facilities, they place as much or more value on protecting both their lives and their environment. On the other hand, transportation companies evaluate projects in terms of the bottom line, i.e., financial considerations outweigh human or environmental factors when determining the merits of a given project. However, when all is said and done, it is the prospective passengers that determine the success or failure of any transportation project. It is the consumer who, in the end, will choose which mode of transportation offers the best value for the money.

It becomes clear that, when taking into consideration the above-mentioned factors, financial considerations alone should not be used to determine the relative merits of a transportation project. It is essential that more emphasis be placed on factors other than economic feasibility in order that the long-range implications, as it relates to the human and natural environments within which it will be built, be properly assessed.

The Japanese Shinkansen has transported more than 2.8 billion passengers since its inauguration in 1964, while enjoying a perfect safety record. Furthermore, the Tokaido-Sanyo Shinkansen line, which runs from Tokyo to Hakata, is the most profitable of the newly formed passenger rail company lines, playing an inportant role in the repayment of their debts, which is a part of the Japanese National Railways reform plan. Of course, the economic growth of Japan is due largely to the Shinkansen, which connects the major population centers. However, the Shinkansen does more than just stimulate economic growth, it creates a sense of community among the people living in Japan. With all of the visible benefits that have been derived from the Shinkansen, the thought of Japan without it is all but inconceivable. In fact, such a notion would not likely occur to anyone living in this country.

Nevertheless, this paper re-evaluates the Shinkansen from the standpoint of energy use, environmental protection and safety. The with-without method is used with the assumption that Japan had never built the Tokaido Shinkansen. The presupositions are 1) unlimited transportation capacity, and 2) the creation of additional accounting units for energy, pollution, fatalities and injuries.

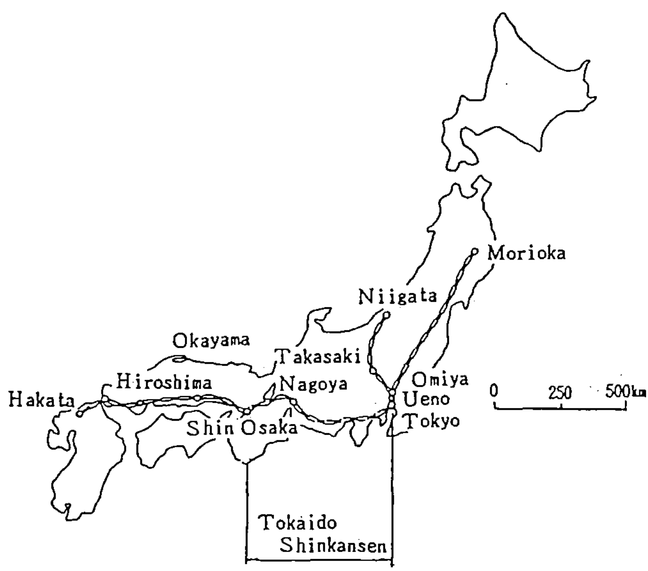
2. FEATURES OF THE SHINKANSEN

2.1 General Description

The Shinkansen was inaugurated between Tokyo and Shin Osaka 25 years ago, on October 1, 1964. Subsequently, the line was extended westward, first between Shin Osaka and Okayama (opened on March 15, 1972), and then between Okayama and Hakata (opened on March 10, 1975). After that, the line was extended northward, first between Omiya and Morioka (opened on June 23, 1982), and then between Omiya and Niigata (opened on November 15, 1982). A section between Ueno and Omiya then began service on March 26, 1985. The line thus connects the main cities of Japan, from the northern district to Tokyo to Hakata, over 1,138 miles (1,832km). (Fig. 1)

The Shinkansen has made fast travel possible between Tokyo and Osaka, Osaka and Hakata, and Ueno and Morioka, in the short times of 2 hr. 56 min., 2 hr. 59 min. and 2 hr. 32 min., respectively, at the maximum speed of 150 mph (240km/h), greatly contributing to the cultural and economic development of the nation. Two types of Shinkansen trains are operated, Hikari (super express) type trains stopping only at principal stations and Kodama (express) type trains serving all stations.

Fig.1 Shinkansen Network in Japan (about 1,830km)



Since it first opened in 1964, a period of 25 years, the Shinkansen has carried over 2.8 billion passengers, more than 100 million a year, without a single casualty due to an accident. The Shinkansen is very energy efficient, consuming only 22% and 19%, respectively, of the energy consumed by airplanes and automobiles. The Shinkansen has thus established itself as a fast, safe, clean and handy transport system for the nation. (Fig. 2, 3, 4)

2.2 Impact of the Shinkansen

The opening of the Shinkansen signified a leap from a 65-mph (100km/h) society to a 130-mph (200km/h) society. This was bound to have a greater impact on the communities along the relevant lines.

The first impact was a direct economic one from the huge investments made for Shinkansen construction. The second impact has been the savings in transportation time and cost made possible by high-speed mass transport capacity, which in turn has had the effect of inducing new traffic. Furthermore, the route of passenger flow has been altered, affecting other competing modes of transportation.

The third impact has been of a regional socio-economic nature, as a result of the foregoing. For instance, shortened travelling time and a reduction in cost has created new opportunities for housing, industrial development,and tourism, contributing to more effective land use in regions where such had been considered difficult.

Fig.2 Ridership of Shinkansen

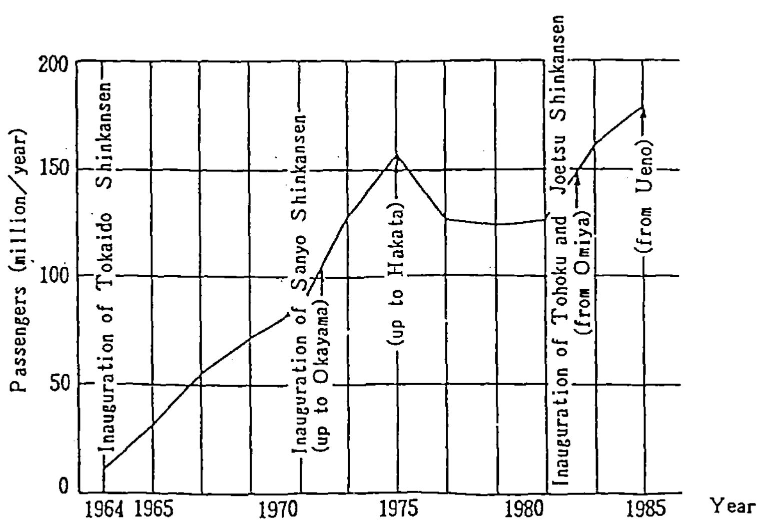
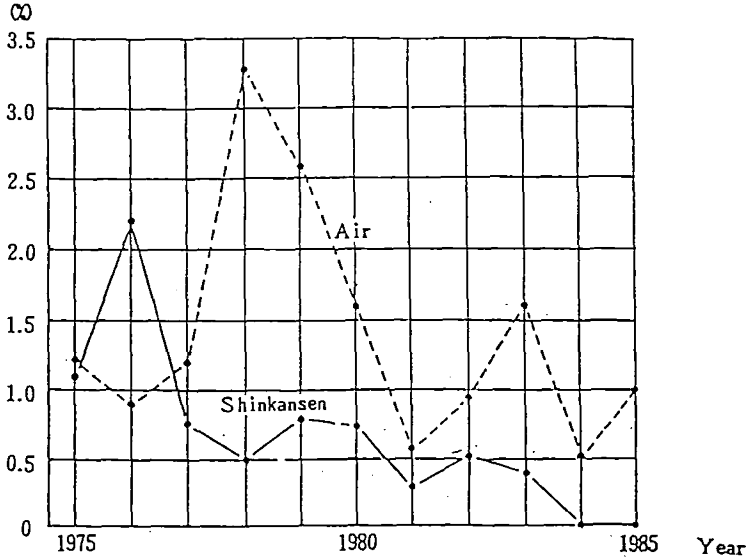
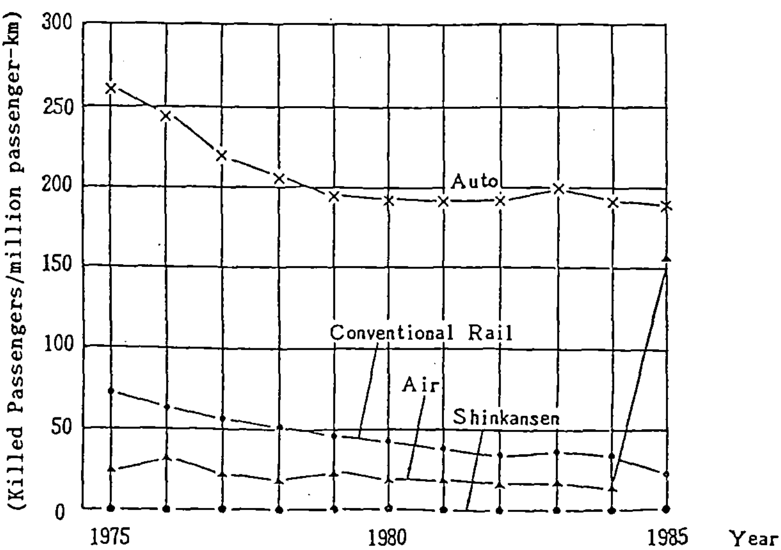


Fig.3 Out of Service Ratio



Note: The Shinkansen data is only for Tokaido and Sanyo.

Fig.4 Number of Fatalities



Note: Auto means cars and buses.

The Tokaido Shinkansen (Tokyo to Shin Osaka) has mainly aimed at short-circuiting and integrating the heavily industrialized and densely populated areas of Tokyo, Nagoya and Osaka; whereas, in the case of the Sanyo Shinkansen (Shin Osaka to Hakata) and the other lines, emphasis has been laid not only on the regions along the route but also on their hinterlands. (Table 1)

The materials and labor needed for the construction of the Tokaido Shinkansen, as well as its impact, are as follows.

1) Construction mileage: 322 miles (515km)
2) Construction period: 1959-1964
3) Amount of materials: cement 1,600,000 tons, steel 460,000 tons, concrete sleepers 1,670,000 pieces
4) Total work force: 35.3 million man-days
5) Impact on employment: 70,000 men/day (average)

This construction promoted the re-development work of areas adjacent to stations.

2.3 Tokaido Corridor Case Study

The reasons why the authors chose the Tokaido Corridor for a case study are as follows.

1) The Shinkansen here connects 300 miles (500km) of the Tokaido megalopolis zone, where conventional railways, express roadways and air services are available for travellers going to and from the big cities of Tokyo and Osaka.
2) Traffic volume is so large that quantitative evaluation is comparatively easy.
3) The biggest three cities in Japan, Tokyo, Nagoya and Osaka, are located on the line and it is not necessary to analyze network routes for alternative modes of transportation.
4) Therefore, the Tokaido Shinkansen is the most suitable example to properly evaluate a hypothetical situation: Japan minus the Shinkansen.

3. MODAL DEMAND RIDERSHIP FORECAST

3.1 Method

There are various of methods for forecasting ridership. Here, the authors estimated the change in modal demand share by travel distance for the cases of with and without for the Shinkansen. Applying this rate of change, the modal share for the without case for the Tokaido Shinkansen was calculated for the transportation modes of conventional rail, auto and air, respectively.

The basic data for the distance-share curve for the with case was the traffic volume of 1985 between Tokyo and Hakata, including the traffic of the Tokaido and Sanyo Shinkansens (750 miles (1,200km)). The data for the without case was the traffic volume of 1980 except all Shinkansen traffic was excluded. From these two basic sets of data, the hypothetical transfer rate of traffic from the with to the without case was obtained.

The result is the modal demand in Tokaido area in 1985 without the Shinkansen.

Table 1. Economic Effects of Transportation Investment (1)

Economic Effects		Direct Effects	Indirect Effects
Internal	Generated by operation	On diverted pass. due to: a. changes in service quality in terms of time savings b. increases(decreases) in costs On induced pass. due to: c. increases in benefits from induced trips (trip value - trip cost) On transportation co. due to: d. increases(decreases) in capital and operating costs e. increases(decreases) in revenue	On transp. co. and users of existing facilities a. changes after the effects from an implemented project b. benefits of transportation companies and users in the generation of traffic
External	Generated by operation	f. disutilities generated along routes that are not compensated for as capital costs g. mitigation of pollution via the reduction in traffic of alternative modes of transport	On areas along the route and the national economy Microscopic: c. increases in consumer demand related to traffic Macroscopic: d. local development e. the mitigation of gaps in the standard of living among local areas
	Generated by investment	h. changes in the value of environmental resorces	f. the multiplier effect of investment in projects g. the multiplier effect of investments related to projects

3.2 Presuppositions

The following are presuppositions for the simplification of the forecasting model.

1) Traffic volume is calculated only between Tokyo, Nagoya and Osaka, since 80% of passenger-km originates and terminates in these three zones of the Tokaido Shinkansen.
2) Transportation capacity is unlimited for all modes, since the purpose of this paper is not to estimate the initial cost but the social cost of transport.

3.3 Modal Demand Share

Fig. 5 is the curve for the modal demand share in the cases of with and without for the Shinkansen.

Sw1 is the curve for the share of air transport in the case of with. Sw2 is the curve for the total share of rail and air transport in the case of with. So1 is the curve for the share of air transport in the case of without. So2 is the curve for the total share of rail and air transport. The individual curves are expressed approximately by the equation in Table 2, where d is a distance (km) and p, q are the parameters.

The areas divided up by the individual curves indicate the different modal demand shares. The air passenger share is below the Sw1 (So1) curve, the auto passenger share above the Sw2 (So2) curve, and the area between these two curves is the rail passenger between Sw1 (So1) and Sw2 (So2), which shows the share of the Shinkansen in the case of with and that of the conventional rail in the case of without, respectively.

In the case of no Shinkansen, its passengers would use conventional rail, auto or air transport in accordance with the ratios of the following formulae.

$$S(d)rail = \frac{\{(So2(d) - So1(d)\} - \{Sw2(d) - Sw1(d)\} \times \{1 - k(d)\}}{\{Sw2(d) - Sw1(d)\} \times k(d)} \quad (1)$$

$$S(d)auto = \frac{Sw2(d) - So2(d)}{\{Sw2(d) - Sw1(d)\} \times k(d)} \quad (2)$$

$$S(d)air = \frac{So1(d) - Sw1(d)}{\{Sw2(d) - Sw1(d)\} \times k(d)} \quad (3)$$

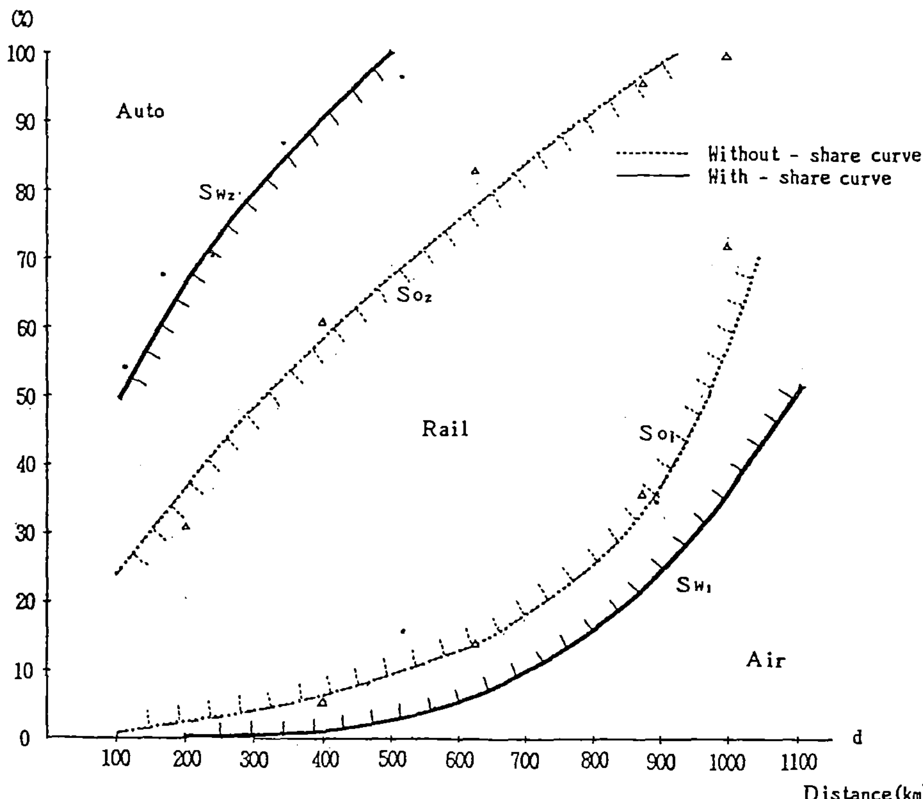
where k(d) is the ratio of Shinkansen passengers for all rail traffic at distance d (km). {Sw2(d)-Sw1(d)} is the ratio of all rail traffic.

3.4 Induced Traffic Volume

The Shinkansen has an inductive effect on total traffic volume. The induced ratio y(%) is expressed by the following formula, as shown in Fig. 6.

$$y = 1.103 - 5.53 \times 10^{-5} \times d , \quad (r = -0.64) \quad (4)$$

Fig.5 Modal Demand Share in the Cases of With and Without the Shinkansen

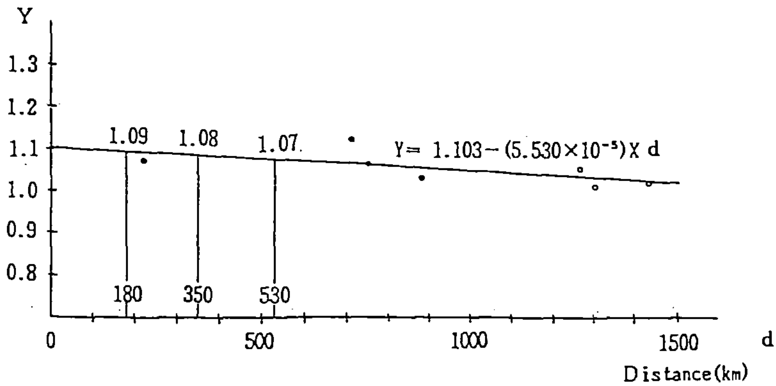


Note: Auto means cars and buses.

Table 2 Parameters $f(d) = p \times d^{q}$

	p	q	Correlation
S_{W1}	3.58×10^{-10}	3.67	0.85
S_{W2}	6.49	0.440	0.98
S_{O1}	5.23×10^{-4}	1.58	0.80
S_{O2}	1.21	0.647	0.99

Fig.6 Induced Ratio by the Shinkansen (1)



3.5 Modal Transfer Ratio

Table 3 is the modal transfer ratio of Shinkansen passengers for the hypothetical situation of Japan minus the Shinkansen, which is derived from the formulae of modal demand share in the cases of with and without the Shinkansen and from the percentage of Shinkansen passengers for all rail traffic.

Table 3 Modal Transfer Ratio of Shinkansen Passengers without the Shinkansen (%)

Distance	OD	Conventional Rail	Auto	Air
180km	Nagoya ～Osaka	31.6	64.4	4.0
350km	Tokyo～Nagoya	55.7	38.6	5.7
530km	Tokyo～Osaka	61.4	31.1	7.5

3.6 Results for With and Without

Total traffic volume is shown in Table 4 for the cases of with and without the Tokaido Shinkansen, which are derived from the rate of induced traffic volume.

Table 4 Total Traffic (passenger/day)

Distance	Induced Ratio	Total Traffic	
		With	Without
180km	1.09	203,850	186,523
350km	1.08	71,960	66,419
530km	1.07	114,224	106,343

The modal demand ridership is shown in Table 5, for each OD pair of the three areas of Tokyo, Nagoya and Osaka, for the cases of with and without the Tokaido Shinkansen, for 1985.

Table 5 Modal Demand in Tokaido (passenger/day, 1985)

OD	With				Without		
	Shinkansen	Conventional Rail	Auto	Air	Conventional Rail	Auto	Air
Nagoya ~ Osaka	27,384	11,465	165,001	0	18,408	167,112	1,003
Tokyo ~ Nagoya	42,709	910	28,111	230	22,797	41,163	2,459
Tokyo ~ Osaka	78,060	425	26,760	8,979	45,018	47,515	13,810

The change in total traffic volume (passenger-km) results is as indicated in Table 6, for each mode of transport.

Table 6 Difference between With and Without

(billion passenger-km/year, 1985)

Shinkansen	Conventional Rail	Auto	Air
Δ22.3	11.9	5.8	1.3

The change in grand total passenger-km is as indicated in Table 7, multiplying 1.24 to Table 6. Note that 1.24 is the rate of total traffic volume (23.7 billion passenger-km) by each OD pair of the three major areas (a total of 19.1 billion passenger-km).

Table 7 Difference between With and Without for All OD Pairs

(billion passenger-km/year, 1985)

Shinkansen	Conventional Rail	Auto	Air
Δ27.7	14.7	7.2	1.6

4. EVALUATION UNITS

4.1 Environment

Three kinds of materials are chosen to evaluate air pollution, including those generated by producing electric power for the operation of railways. The units are shown in Table 8, in tons per billion passenger-km. They are derived from the data in official reports. (2)(3)

Table 8 Air Pollution by Transport Mode (2)(3) (ton/billion passenger-km)

Mode	CO	NOx	SOx	Traction
Shinkansen	2.30	0.31	0.18	electric
Conventional Rail	1.62	0.22	0.13	electric
Auto	4.03	5.73	0.18	fuel
Air	105.23	20.21	2.69	fuel

4.2 Energy

The energy consumption units are shown in Table 9, in kcal/passenger-km, taking into consideration the load factor of each transportation mode. The energy loss, when expressed in liters of oil, 9,400 kcal/liter. Load factors are 50% for Shinkansen, 43.1 person/car for conventional rail, 1.3 person/car for auto, 18.3 person/car for bus and 70% for air.

Table 9 Energy Consumption by Transport Mode (4) (kcal/passenger-km)

Shinkansen	136kcal
Conventional Rail	96kcal
Auto	631kcal
Air	714kcal

4.3 Safety

The units of safety are shown in Table 10, in men/passenger-km, which are calculated by dividing the annual number of fatalities and injuries by traffic volume. The total number of units for conventional rail includes non-on-board casulties as well as on-board passengers. On the other hand, the units for autos exclude those casualties, since almost all cars and buses supposedly use express roadways where the only people injured are on-board passengers.

Table 10 Level of Safety (1) (passenger/million passenger-km)

		Shinkansen	Conventional Rail	Auto	Air
On-board	Fatalities	0	0.32	54.6	22.6
	Injuries	0	24.4	950.7	3.1
Non-on-board	Fatalities	0	4.1	0	0
	Injuries	0	22.0	0	0
Total	Fatalities	0	4.4	54.6	22.6
	Injuries	0	46.4	950.7	3.1

5. RE-EVALUATION OF THE SHINKANSEN

5.1 Quantitative Evaluation

A quantitative evaluation of the Shinkansen is shown in Table 11, for the case of Japan minus the Tokaido Shinkansen. In 1985, if no Shinkansen had existed, an additional 37,312 auto passengers and 8,235 air passengers would have had to travel daily, in addition to an additional 76,144 conventional rail passengers.

In this case, the required energy would amount to 360 million liters a year, which is equal to the consumption of 1.1 million families in Japan. The number of fatalities would have totaled 50, and that of injuries would have come to 755, respectively. As for pollutants being released into the environment, an additional 15,690 tons of CO, 6,820 tons of NOx and 250 tons of SOx would have been emitted. The amount of pollutants is almost equal to that for a year in Tokyo (1988) and that for two months in Los Angeles (1974).

The accumlated data for the without case is also shown in Table 11, roughly totalling the additional energy, casualties and pollutants for the 25 years since 1964. Here, the additional energy amounts to 8,300 million liters, the number of fatalities and injuries 1,150 and 17,520, and there would have been additional tons of pollutants inevitably emitted.

5.2 Calculation of Social Costs

Individual terms should be evaluated monetarily, though it is quite difficult to value the social cost of the environment, energy and safety. (Table 12)

Table 12 Total Social Cost (billion yen, in 1985)

Evaluation	Environment	Energy	Safety	Total
1985	1.0	15.1	9.0	25.1
Since 1964	22	350	207	579

Acording to a 1988 report by the Worldwatch Institute in the US, countermesures for the different kinds of pollution that cause on a global scale such phenomena as the greenhouse effect, desertification, ozon layer destruction, and the extinction of animal species, along with mesures that will continue to promote previous environmental gains, will require the enormous sum of 1.5 trillion dollars (20 trillion yen) for the next ten years.

In the case of there being no Tokaido Shinkansen, the environmental restoration cost out of the above 20 trillion yen would be estimated by multiplying an energy consumption ratio of 360 million liters / 7,426,200 million liters, which would equal 1.0 billion yen. Here, the figure 7,426,200 million liters is the oil conversion of world energy consumption in 1987. The authors should admit that the cleanliness of energy consumption is not considered yet.

The cost of energy loss would be calculated by the imported oil price (1985), which is 42.37 yen/liter.

Table 11 Quantitative Evaluation

Item			1985					Since 1964
			Shinkansen	Conventional Rail	Auto	Air	Total	Total
Traffic	(passenger／day)		△143,298	76,144	37,312	8,235	—	—
	(billion passenger-km／year)		△ 27.7	14.7	7.2	1.6	—	—
Environment	CO (ton)		△ 6,380	2,390	2,910	16,760	15,690	363,900
	NOx (ton)		△ 860	320	4,140	3,220	6,820	158,200
	SOx (ton)		△ 500	190	130	430	250	5,800
Energy	Energy (billion kcal)		△ 3,770	1,410	4,550	1,140	3,340	77,400
	Energy in petrol (million liter)		△ 400	150	490	120	360	8,300
Safety	Fatalities	on-board (person)	△ 0	0.5	39.4	3.6	44	1,010
		Total (person)	△ 0	6.5	39.4	3.6	50	1,150
	Injuries	on-board (person)	△ 0	35.9	686.2	0.5	723	16,770
		Total (person)	△ 0	68.3	686.2	0.5	755	17,520

Human loss is expressed as the loss in production to society. Assuming the amount produced can be measured by wages, human loss can be regarded as a loss in those wages. Of course, human life is not something that should usually be valued in terms of money only. However, estimating a person's lifetime wages at about two hundred million yen (in 1985 prices), and that the average age for accident fatalities is 35.6 years old, the loss of a human life is about 180 million yen. The lifetime wages of a person from 20 to 60 years of age are assumed to be linear in progression. If there had been no Shinkansen since it first opened in 1964, the number of traffic fatalities would have been 1,150 persons, or 207 billion yen in production would have been lost. Note that this figure for production loss does not include those who are injured.

5.3 Re-evaluation of Tokaido Shinkansen

The Tokaido Shinkansen's construction was not nationally subsidized, but financed by a World Bank loan (80 million dollars in 1961 prices at 5.75% interest), and the Shinkansen was able to make a profit in only four years (1968). In addition to this, the Shinkansen activated the economies of local areas and, as shown by this study on the environment, energy, and safety, resulted in a savings of approximately 579 billion yen. If we estimate the cost of the Tokaido Shinkansen's construction in 1985 prices, which is about 2.2 trillion yen, the savings (even with a conservative figure) would still compensate for one-quarter of the cost.

6. CONCLUSION

With the progress of cultural development, the activities of human beings have even started to produce global impacts of an uneconomical nature. For example, the worsening of the environment due to air pollution and the like, and such phenomena as the warming of the earth, which might cause tremendous damage if it continues at the pace that has been reported. Energy problems have also become international topics in such respects as the destruction of the environment from the burning of fossil fuels. On the other hand, policies that put weight on the life style of the individual rather than on a business-oriented way of thinking have started to multiply. At the same time, as society is becoming more and more complicated, information for the individual is gaining in importance. Thus, we have reached the stage where great attention should be paid to the loss or injury of human life. In Europe, the scope for evaluation has become broader as a result of including environmental problems in the policy decisions of transportation projects such as the West German ICE and French TGV (West Coast line). However, transport projects had only been evaluated from the viewpoint of profitability. In recent years, though, external economics (such as the inducement of production and increase in enployment) have also been considered.

In this paper, it has been shown that external economies, from a quantitative point of view, have a large effect. Unfortunately, the method for evaluating these external economies (environmental preservation, energy efficiency, safety) are still inadequate.

When considering the influence that we transportation specialists have on the future of mankind via transportation projects, and the extremely long effects that such projects have on capital formation, we have reached the stage where it is necessary to have a broader scope (i.e. global in the economic and human aspects) when evaluating transportation projects, by including environmental, energy, and safety concerns at the time when decisions on transportation policy and subsidies are being made.

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