THE EFFECT OF THE SPREAD OF EXPRESSWAY NETWORK ON TRAFFIC DEMAND IN JAPAN

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Abstract: In Japan, where expressway development has advanced rapidly, it is conceivable that not only the reduction in general expenditure or time required to travel between zones but also the spread of the expressway network itself due to psychological factors affects road traffic demand. From this aspect, macro road traffic demand model for passenger for travel behavior of various purposes and for freight is developed. Using the model, the effect of future expressway development on road traffic demand all over Japan is measured and the operating feasibility in finance of some expressways in Japan is verified by comparing the expenses associated with road development with the increased toll revenue from the increased traffic demand. As a result, the development of a rural expressway with a potential demand thought to be small in Japan turned out to be feasible from the financial viewpoint.

Keywords: travel demand model, expressway network, operating feasibility in finance

1. INTRODUCTION

Traffic demand for passengers and freight in Japan is showing a consistent increase since the World War Ⅱ, and with progressive motorization the increase in road traffic demand in particular has been very large, the increase factors between 1965 and 1995 being about 3.4 times for passengers (passenger-kilometers) and 2.8 times for freight (ton-kilometers). Meanwhile, the length of roads has increased steadily during this period with 6,375 km of expressways and 25,298 km of ordinary national roads being developed.

Up to now, the expressway development has been aimed at satisfying the demand for the transportation of passengers and freight that supports economic growth. Therefore great importance has been attached to the development of longitudinal expressways as the main arteries of national transportation and this has greatly shortened the time and distance between the north and south of Japan. It seems that there will be no great increase in the amount of traffic from now on due to the declining population and slowing of economic growth. Consequently the need has now arisen to review the way expressways should be developed to be just sufficient to cope with traffic demand.

In considering the level of expressway development from now on, it is extremely important to study the practical feasibility of expressway development from the financial viewpoint, too.

With this background, the objectives of this paper are as follows. 1) Outline the historical changes in the expressway network in Japan up to now. 2) Develop a macro model capable of measuring the effect of the spread of the expressway network on road traffic demand. 3) Measure the effect of future expressway development on road traffic demand all over Japan. 4) Propose a method of verification of the operating feasibility in finance by comparing the expenses associated with road development with the increased toll revenue from the increased traffic demand.

2. HISTORICAL CHANGES IN THE EXPRESSWAY NETWORK IN JAPAN

Japan's first expressway, the Meishin Expressway from Nagoya to Kobe was available for use in 1964, the year of the Tokyo Olympics. The Tomei Expressway from Tokyo to Nagoya was opened to traffic in 1969, which meant that Tokyo and Kobe were connected by a main arterial expressway. The 1970s saw a steady spread of the expressway network and by the 1980s the piercing of Japan from north to south by longitudinal expressways was almost complete. Construction of transverse expressways at right angles to the longitudinal expressways began in the 1990s. In 1980 the total length of Japan's national expressways was 2,832 km but in 1999 this has reached 7,377 km. Figure 1 shows the changes in length of expressway and ordinary arterial road in Japan, and Figure 2 and 3 show the changes in the expressway network in Japan.

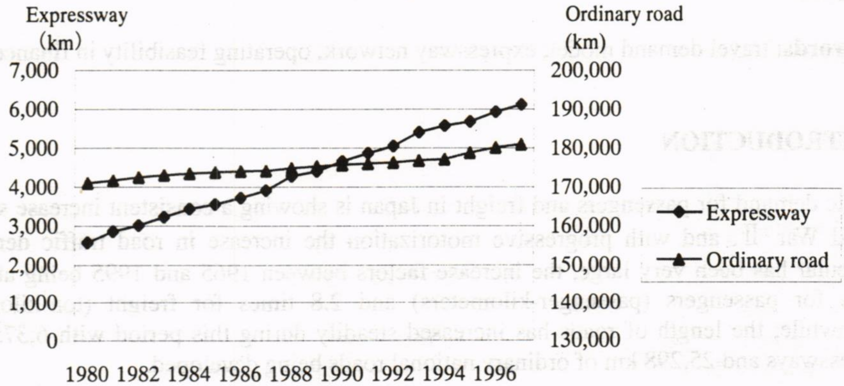


Figure 1. Changes in the length of expressway and ordinary arterial road in Japan

Source: Ministry of Construction, Road Statistics Annual Report

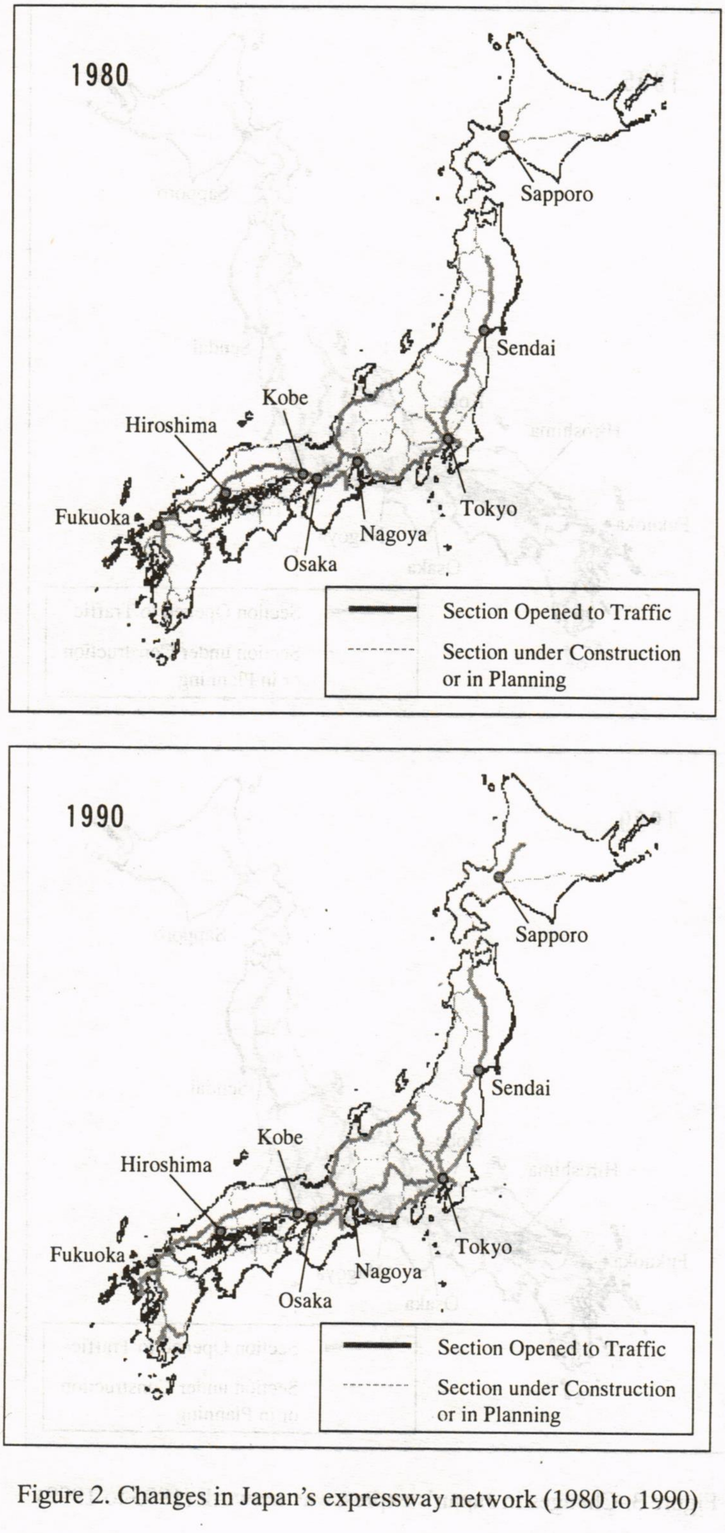
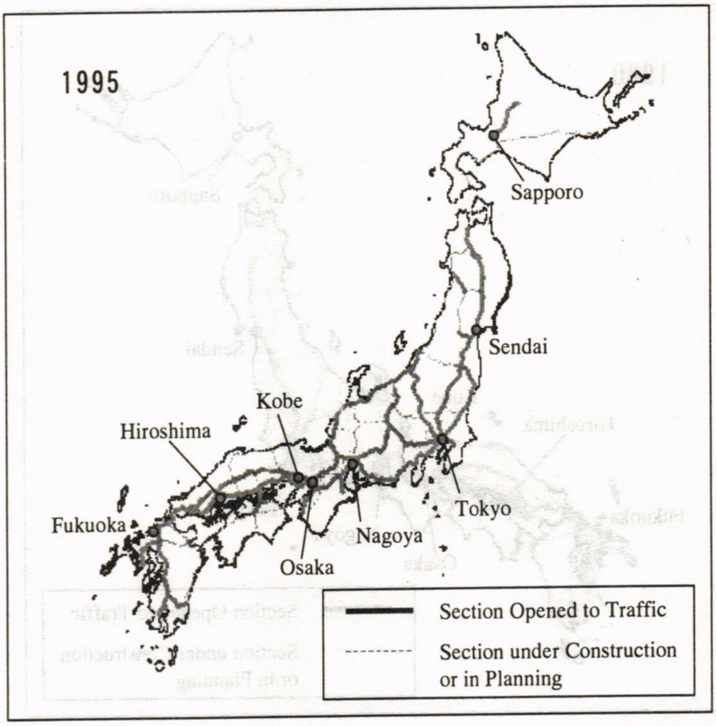


Figure 2. Changes in Japan's expressway network (1980 to 1990)



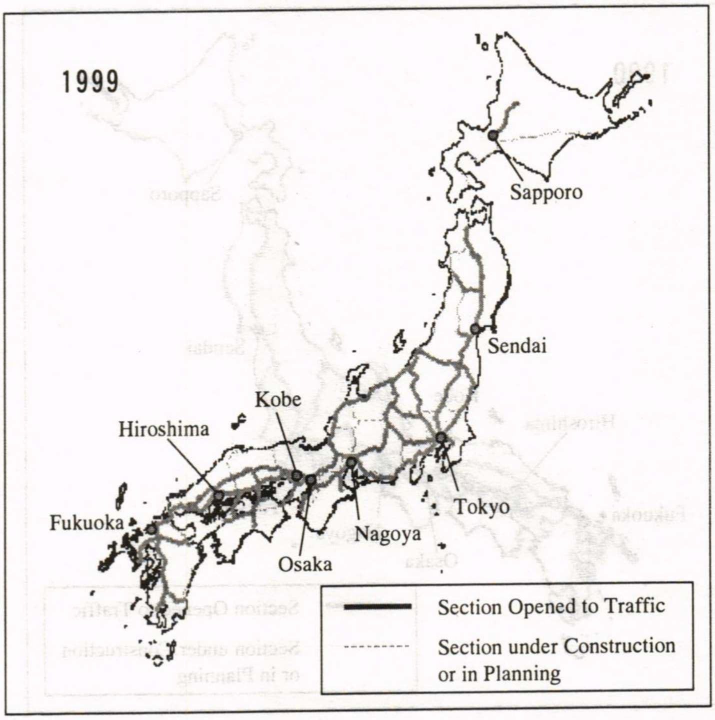


Figure 3. Changes in Japan's expressway network (1995 to 1999)

3. ANALYSIS OF CAUSES OF ROAD TRFFIC DEMAND

3.1 Road traffic demand functions

In general, the demand of an individual or a household for goods or services is determined by prices and real income and the demand function can be expressed by Equation (1).

$$D = f(P,Y) \tag{1}$$

Here,
D : demand for goods or services
P : price of goods or services
Y : real income

It is also possible to express road traffic demand basically as a function of the average generalized expenditure required for road usage and real income, as in Equation (2).

$$Flow_{road} = f(P_{road},Y) \tag{2}$$

Here,
$Flow_{road}$: road traffic demand
P_{road} : average generalized expenditure on road usage
Y : real income

In a case where it is conceivable that service levels will fluctuate widely due to the rapid spread of the expressway network as in Japan, we can assume that not only the generalized expenditure but also the spread of the expressway network itself will generate a new induced demand. In this case, Equation (2) can be transformed into Equation (3).

$$Flow_{road} = f(P_{road},Y,NET_{road}) \tag{3}$$

Here,
$Flow_{road}$: road traffic demand
P_{road} : average generalized expenditure on road usage
Y : real income
NET_{road} : variable expressing (the existence of) expressway network spreading

3.2 Formulation of road traffic demand functions for passengers and freight

In this paper, functions based on Equation (3) are formulated for road traffic demand for passengers (passenger-kilometers) for various trip purposes (for commuting to work and school, business or private purposes) and road traffic demand for freight (ton-kilometers).

Here, average generalized expenditure on road usage P_{road} can be transposed by average time required by road T_{road}, according to the result of SASAKI.K et al. (1999) which showed that elasticity of road traffic demand to toll level is very small in Japan.

$$P_{road} = T_{road} \tag{4}$$

Considering data restrictions or data reliability, the other explanatory variables from Equation

(3) have been also transposed as follows:

$$Y = GDP/POP \tag{5}$$

$$NET_{road} = CNI \tag{6}$$

Here,

GDP : real gross domestic product

POP : population

CNI : expressway connectivity index

The average time required by road T_{road} and expressway connectivity index CNI are defined as follows to reflect the relative importance between zones:

$$T_{Road} = \frac{\sum_i Q^i \cdot T^i_{Road}}{\sum_i Q^i} \tag{7}$$

$$T^i_{Road} = \frac{\sum_i Q^{ij} \cdot t^{ij}}{\sum_i Q^{ij}} \tag{8}$$

$$CNI = \frac{\sum_i POP^i \cdot CNI^i}{\sum_i POP^i} \tag{9}$$

$$CNI^i = \frac{\sum_j POP^j \cdot cni^{ij}}{\sum_j POP^j} \tag{10}$$

Here,

i, j : zones

T^i_{road} : average time required by road from zone i to another zone

Q^i : amount of concentrated traffic generated in zone i

t^{ij} : time required on road from zone i to zone j

Q^{ij} : amount of OD traffic from zone i to zone j

CNI^i : expressway connectivity index for zone i

POP^i : population of zone i

cni^{ij} : degree of connectivity due to expressway from zone i to zone j (1 if connected by expressway, 0 if not connected between zone i and zone j)

Equation (8) shows that the average time required by road in zone i is defined in accordance with the average time required for travel as far as zone j, weighted according to the amount of origin-destination (OD) traffic between i and j. This means that the average time required by road in zone i will be given an importance in accordance with the time required to travel to a zone with a high OD traffic volume. Similarly, Equation (10) shows that the expressway connectivity index for zone i is defined in accordance with the average degree of expressway connectivity with zone j weighted according to the population of zone j.

As a result of this, the demand per person for road traffic (passenger-kilometers) for each passenger trip purpose (for commuting to work and school, business or private purposes) and for road traffic for freight (ton-kilometers) are formulated as shown in Equation (11).

$$\frac{Flow_{road}}{POP} = f\left(\frac{GDP}{POP}, T_{road}, CNI\right) \tag{11}$$

Here,

$Flow_{road}$: road traffic demand for passenger (passenger-kilometers) for each passenger trip purpose (for commuting to work and school, business or private purposes) or road traffic demand for freight (ton-kilometers)

POP : population

GDP : real gross domestic product

T_{road} : average road time required by road

CNI : expressway connectivity index

Transforming Equation (11), the traffic demand for road for an entire zone (passenger-kilometers or ton-kilometers) can be calculated as:

$$Flow_{road} = POP \cdot f\left(\frac{GDP}{POP}, T_{road}, CNI\right) \tag{12}$$

3.3 Data for estimation

In order to analyze the causes of road traffic demand, it is necessary to particularize Equation (11) for specific functions for passengers (for each purpose) and freight and use time series for each variable to estimate the parameters. Figures 4 to 6 show road traffic demand (passenger-kilometers and ton-kilometers) and the time series data for each explanatory variable used for Equation (11).

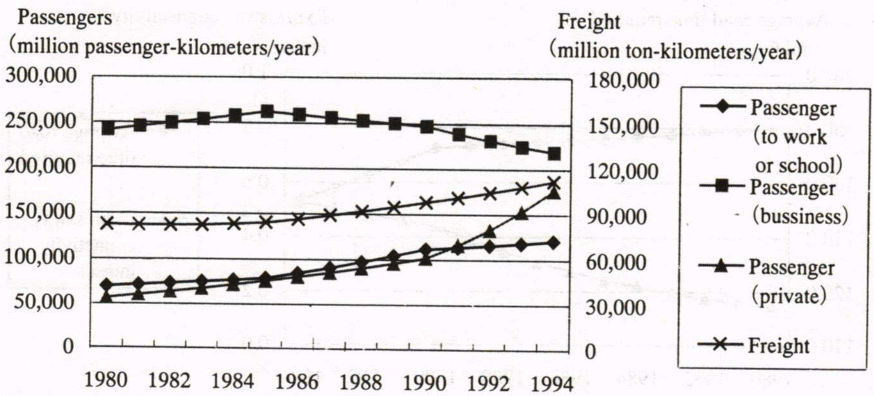


Figure 4. Road traffic demand per person

Source: (Traffic demand) Ministry of Construction (1980, 1985, 1990 and 1994), Road Traffic Census
(Population) Management and Coordination Agency (1980, 1985, 1990 and 1995), **National Census Report**

Note: Traffic demand values for years other than 1980, 1985, 1990 and 1994 have been interpolated in accordance with the rate of increase.
Population values for years other than 1980, 1985 and 1990 have been interpolated in accordance with the rate of increase.

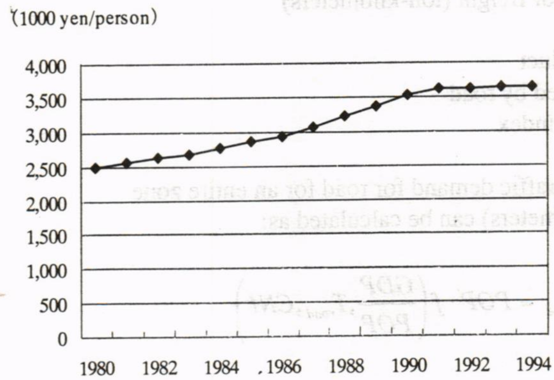


Figure 5. GDP per person (real, 1990 = 1)

Source: (GDP) Economic Planning Agency (annually), **Annual Report on National Economy Calculations**
(Population) Management and Coordination Agency (1980, 1985, 1990 and 1995), **National Census Report**
Note: Population values for years other than 1980, 1985 and 1990 have been interpolated in accordance with the rate of increase.

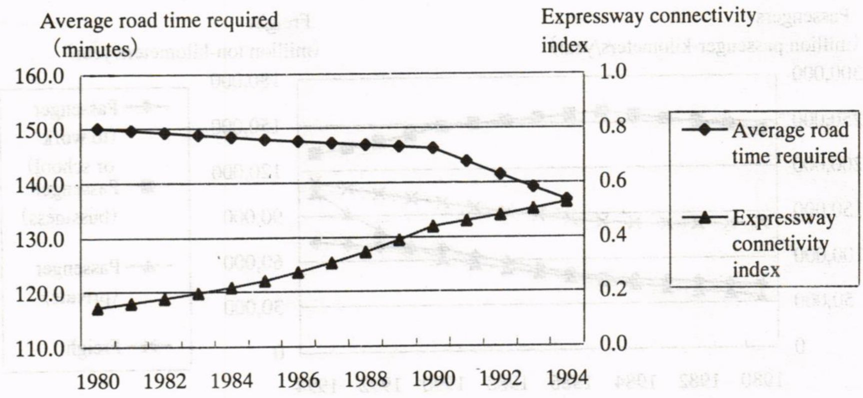


Figure 6. Average road time required and expressway connectivity index

Source: (Average road time required) Compiled from **Road timetables**, Ministry of Construction (annually)
(Expressway connectivity index) Compiled from **Expressway Map**, Japan Highway Corporation (annually)

In Equations (7) to (10), zones to calculate average times required by road and expressway connectivity indices were established in 207 zones throughout Japan as shown in Figure 7.

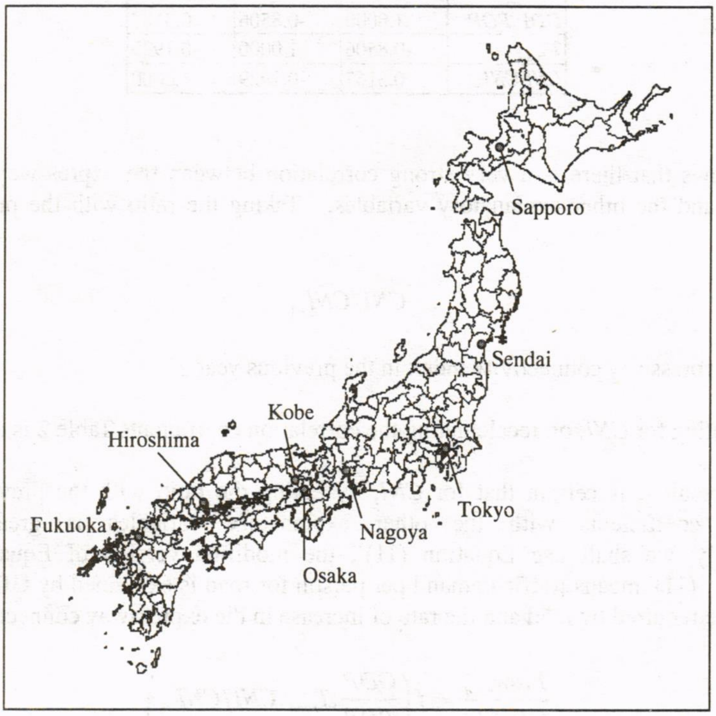


Figure 7. Partitioning of zones

3.4 Varification of validity of data for estimation

When the least squares method is used for the estimation of a function with several explanatory variables, such as Equation (11), it is well known that multi-collinearity will occur if there is a strong correlation between the explanatory variables and estimating appropriate parameters becomes difficult. Table 1 shows the correlation matrix between the explanatory variables of Equation (11).

Table 1. Correlation matrix between the explanatory variables (1980 to 1994)

	GDP/POP	T_{road}	*CNI*
GDP/POP	1.0000	-0.8506	0.9937
T_{road}	-0.8506	1.0000	-0.9009
CNI	0.9937	-0.9009	1.0000

Note: (shaded) correlation coefficients of 0.9 or more

Table 2. Amended correlation matrix between the explanatory variables (1981 to 1994)

	GDP/POP	T_{road}	CNI/CNI_{-1}
GDP/POP	1.0000	-0.8506	0.3167
T_{road}	-0.8506	1.0000	-0.1929
CNI/CNI_{-1}	0.3167	-0.1929	1.0000

Table 1 shows that there is a very strong correlation between the expressway connectivity index *CNI* and the other explanatory variables. Taking the ratio with the previous year's *CNI*,

$$CNI/CNI_{-1}$$

here,

CNI_{-1} : expressway connectivity index in the previous year

and substituting for *CNI*, on recalculating the correlation coefficients Table 2 is obtained.

From this result it is certain that for *CNI*, by taking the ratio with the previous year the correlation coefficients with the other explanatory variables is greatly reduced. Consequently, we shall use Equation (11)', the modified version of Equation (11) for estimation. (11)' means traffic demand per person for road is explained by GDP per person, average time required by road and the rate of increase in the expressway connectivity index.

$$\frac{Flow_{road}}{POP} = f\left(\frac{GDP}{POP}, T_{road}, CNI/CNI_{-1}\right) \tag{11)'$$

3.5 Estimation of road traffic demand functions

Equation (11)' was particularized to the function type such as Equation (11)" and the estimations was carried out using the time series data (1981 to 1994) for each variable shown in Figures 4 to 6.

$$\frac{Flow_{road}}{POP} = \alpha \cdot \left(\frac{GDP}{POP}\right)^{\beta} \cdot T_{road}{}^{\gamma} \cdot (CNI/CNI_{-1})^{\delta} \tag{11)''$$

The estimation was made, actually, by taking the logarithms of both sides and transforming as follows:

$$\ln\frac{Flow_{road}}{POP} = \alpha' + \beta \ln\left(\frac{GDP}{POP}\right) + \gamma \ln T_{road} + \delta \ln(CNI/CNI_{-1})$$

Table 3. Results of the estimations

Passengers /Freight	Purpose	Constant term	*GDP /POP*	T_{road}	*CNI / CNI*$_{-1}$	R^2
Passenger person-km	Commuting to work or school	2.1746 (0.85)	1.2211 (16.82**)	-0.7735 (-1.53*)	0.2109 (0.66)	0.9840
		0.9234 (0.55)	1.2351 (18.25**)	-0.5216 (-1.59*)		0.9890
	Business	-8.1006 (-3.18)	-0.0717 (-0.99)	1.7761 (3.53)	0.3804 (1.20)	0.9243
		-10.3577 (-5.88)	-0.0465 (-0.66)	2.2305 (6.55)		0.9212
	Private	39.2662 (37.10)	0.8358 (27.91**)	-8.1390 (-38.91**)	0.5271 (4.02**)	0.9994
Freight ton-km	—	7.6708 (3.33)	0.3285 (5.03**)	-1.6683 (-3.66**)	-0.1683 (-0.59)	0.9642
		8.6693 (5.72)	0.3173 (5.24**)	-1.8693 (-6.38**)		0.9663

Note: The lower figures in parentheses are t-values; ** indicates significnat at 1% level, and * indicates significnat at 10% level.
Estimation period: 1981 to 1994

Table 3 shows the results of the estimations. The results of the estimations have clarified the following two points. Firstly, only passenger travel for private purposes is affected by the growth of expressway connectivity. The growth of expressway connectivity does not affect traffic demand for passengers commuting to work and school or for freight. Secondly, elasticity of traffic demand for private purposes to the average time require by road is about -8.1, which is very much greater than for other purposes and freight. As a reason for the road traffic demand for passenger travel for private purposes being influenced by the growth of expressway connectivity, it is conceivable that in the case of passenger travel for private purposes the spread of the expressway network itself arouses a short-term demand for road traffic due to primary psychological factors.

No significant parameter could be obtained for passenger travel for business purposes. As shown in Figure 4, this may be due to the recent decrease in road traffic demand caused by some factor other than economic factors and expense, such as a switchover to telecommunication from face-to-face business activity.

4. PREDICTING ROAD TRAFFIC DEMAND ACCOMPANYING ROAD DEVELOPMENT AND VERIFICATION OF FINANCIAL FEASIBILITY

4.1 Outline

Using the estimated Equation (11)" enables road traffic demand associated with future road development or changes in population and GDP to be predicted for freight and for passenger travel for private purposes or for commuting to work or school. In the case of expressway development in particular, both the average time required by road T_{road} and the expressway connectivity index *CNI* are variable in Equation (11)" and the increase in traffic demand for road associated with varying them can be estimated.

In addition, by comparing the increase in long term toll revenue associated with increased road traffic demand with road construction costs and maintenance and management expenses at current values, it is possible to verify the operating feasibility in finance of a particular road easily.

4.2 Predicting road traffic demand accompanying expressway development

The simulations of the effect on road traffic demand of the development of the Kita-kanto Expressway (Mito - Tochigi - Takasaki, about 150 km, roadside zone population about 4.09 million) with a potential demand thought to be comparatively large and the Japan Sea coast Tohoku Expressway (Niigata - Sakata - Akita, about 265 km, roadside zone population about 2.04 million) with a potential demand thought to be comparatively small are conducted. The implementation of the simulations is for a year of 2010. Figure 8 shows the roads for simulation.

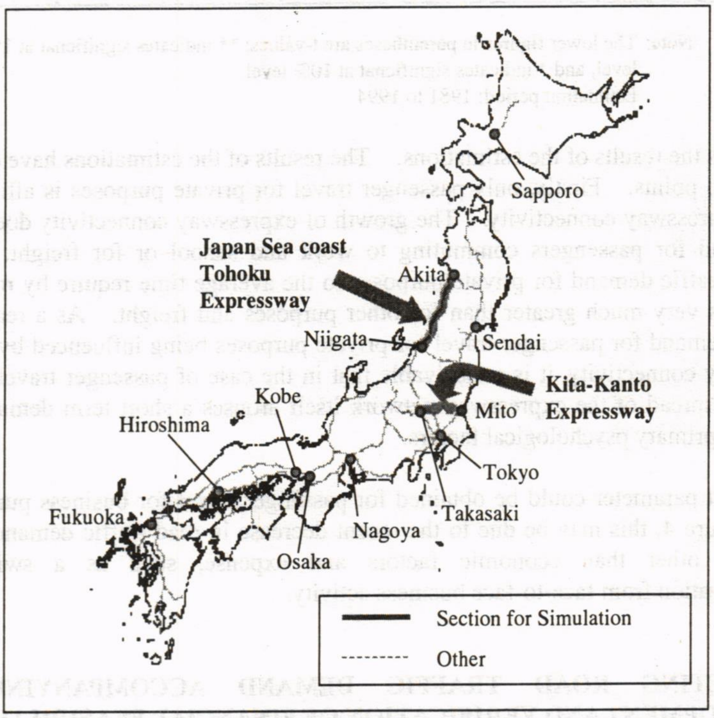


Figure 8. Roads for simulation

In the simulation, it is assumed that the development of the Kita-kanto Expressway and the Japan Sea coast Tohoku Expressway would enable to drive the roadside zones at 80 km/h. Times required by road and connectivity by expressway between every zone throughout the nation are established on this basis and the average time required by road T_{road} and the expressway connectivity index *CNI* are calculated for the cases where the roads have been developed. The average time required by road and expressway connectivity index for the cases where the roads will not be developed are taken to be the values for the most recent year of 2000. Table 4 shows the average time required by road and expressway connectivity index for three simulation cases (the case in which there is no road development, the case in which the Kita-kanto Expressway has been developed and the case where the Japan Sea coast Tohoku Expressway has been developed).

Table 4. Average time required by road and expressway connectivity index for three simulation cases

		Average road time required *TROAD*	Expressway connectivity index *CNI*	Increase in express-way connectivity index CNI/CNI_{-1}
Without road development		134.50	0.6584	1.0359
With road development	Kita-kanto Expressway	133.64	0.6645	1.0455
	Japan Sea coast Tohoku Expressway	133.86	0.6625	1.0424

For the simulations, GDP and population in 2010 were determined as follows:

GDP: 562,154 billion yen (assuming 1.9% growth from 2000)
Population: 127,620 thousand (estimated by National Institute of Population and Social Security Research in Japan)

At this time, GDP per person becomes 4,405 thousand yen.

Table 5 shows the results of simulations based on the above external variables. Trial calculations were made with traffic demand for passenger travel for business purposes fixed at the latest value.

From the results it is certain that developing these roads will have an extremely large impact on traffic demand for passenger travel for private purposes all over Japan, being 5.84% in the case of the Kita-kanto Expressway and 4.25% in the case of the Japan Sea coast Tohoku Expressway.

Table 5. Simulation results

Passengers / Freight		Passengers (million passenger-kilometers/year)				Freight (million ton-kilometers/year)
Purpose		Commuting to work or school	Business	Private	Total	
Without road development		155,543	218,294	239,767	613,604	124,770
With road development	Kita-kanto Expressway	156,062	218,294	253,770	628,126	126,267
	Japan Sea coast Tohoku Expressway	155,926	218,294	249,952	624,172	125,873
With minus without road development	Kita-kanto Expressway	519	—	14,003	14,522	1,497
	Japan Sea coast Tohoku Expressway	383	—	10,184	10,567	1,103
With minus without road development, rate of increase	Kita-kanto Expressway	0.33%	—	5.84%	2.37%	1.20%
	Japan Sea coast Tohoku Expressway	0.25%	—	4.25%	1.72%	0.88%

4.3 Verification of operating feasibility in finance

A comparison between costs and increase in revenue associated with developing the two expressways provides a simple way of verification in finance of each route for the constructor. The costs for the constructor are construction costs and maintenance and management expenses. The revenue for the constructor becomes the increased toll revenue associated with increased road traffic demand.

First calculate the vehicle-kilometers traveled by passenger vehicles and freight vehicles by multiplying passenger-kilometers and freight ton-kilometers by the average numbers of passengers per vehicle for each purpose and average load weight respectively.

Table 6. Variations in vehicle-kilometers traveled as a result of road development

Passengers / Freight		Passengers				Freight
Purpose		Commuting to work or school	Business	Praivate	Total	
Average number of passengers (person/vehicle)		1.10	1.81	1.96		
Average load weight (ton/vehicle)						0.4925
Vehicle-kilometers						
Without road development (million vehicle-kilometers)		141,403	120,604	122,330	384,338	253,340
With road development (million vehicle-kilometers)	Kita-kanto Expressway	141,874	120,604	129,474	391,953	256,380
	Japan Sea coast Tohoku Expressway	141,751	120,604	127,526	389,882	255,580
With minus without road development (million vehicle-kolometers)	Kita-kanto Expressway	472	—	7,144	7,616	3,040
	Japan Sea coast Tohoku Expressway	348	—	5,196	5,544	2,240

Source: (Average passengers and average load weight) Ministry of Construction (1994), **Road Traffic Census, Vehicle Origine-Destination Survey**

Table 7. Variations in toll revenue as a result of road development.

Passengers / Freight		Passengers (ordinary cars)	Freight (large vehicles)	Total
Expressway toll per km		24.6	40.59	
Toll revenue (million yen/year)				
Without road development (million vehicle-kilometers)		3,478,513	10,283,073	13,761,586
With road development (million vehicle-kilometers)	Kita-kanto Expressway	3,490,112	10,406,479	13,896,591
	Japan Sea coast Tohoku Expressway	3,487,070	10,374,010	13,861,080
With minus without road development (million vehicle-kilometers)	Kita-kanto Expressway	11,599	123,406	135,005
	Japan Sea coast Tohoku Expressway	8,557	90,938	99,495

Table 8. Road construction costs and maintenance and management expenses

	Construction cost per km (million yen/km)	Maintenance and management expense per km (million yen/km)	Road Length (km)	Construction cost (million yen)	Maintenanse and management cost (million yen/year)
Kita-kanto Expressway	4,860	52.2	150	729,000	7,823
Japan Sea coast Tohoku Expressway	4,030	52.2	265	1,067,950	13,821

Source: Compiled from **JH Annual Reports**, Japan Highway Public Corporation (1999)

Table 9. Comparison of increased toll revenue and total cost during the project period

	Per year		40-year total				
	Tool revenue increase (million yen)	Maintenance and management expense (million yen)	Tool revenue increase (million yen)	Construction cost (million yen)	Maintenance and management expense (million yen)	Total cost (million yen)	Toll revenue increase /Total cost
Kita-kanto Expressway	135,005	7,823.3	2,778,411	729,000	161,003	890,003	3.12
Japan Sea coast Tohoku Expressway	99,495	13,821.1	2,047,598	1,067,950	284,439	1,352,389	1.51

Then apply the expressway toll per kilometer for passenger vehicles and freight vehicles to the vehicle-kilometers traveled by passenger vehicles and freight vehicles to obtain the toll revenue for one year. Here, it is assumed that the expressway toll per kilometer in the future is fixed at the latest value. Table 6 and 7 show variations in vehicle-kilometers traveled and variations in toll revenue as a result of road development.

The construction costs and maintenance and management expenses for the Kita-kanto Expressway and Japan Sea coast Tohoku Expressway are estimated as table 8. Here the different road construction costs per kilometer were calculated on the basis that certain sections on each route have already been completed.

A 40-year project period and discount rate of 4% are assumed. At this time, if the year when service begins is taken to be the standard year, the comparison of increased toll revenue and costs due to road development during the project period is as shown in Table 9.

From the above, the ratio of toll revenue increase and total cost of 3.12 for the Kita-kanto Expressway is extremely high and for the Japan Sea coast Tohoku Expressway it is 1.51, which is larger than 1.0. Consequently, the development of both routes is quite feasible from the financial viewpoint.

5. CONCLUSION

The following knowledge has been obtained from this paper.

1) Average times required by road in Japan affect traffic demand for road for passengers and freight but the effect on traffic demand for passenger travel for private purposes in particular is extremely large.

2) In Japan, where expressway development has advanced rapidly, the "expressway connectivity index" defined by the weighted average for population of connectivity between zones that equals to 1 if zones are connected by expressway and equals to 0 if not connected affects traffic demand for passenger travel for private purposes.

3) A comparison between the increase in toll revenue associated with the increase in traffic demand obtained from macro model and costs associated with road development enables the operating feasibility in finance to be verified easily.

4) As a result of comparison between toll revenue and costs associated with road development for an expressway with a potential demand thought to be small in Japan, the development turned out to be feasible from the financial viewpoint.

The assignments in building a traffic demand model that can be used for studying a more detailed verification of operating feasibility in finance and the social adequacy are as follows.

1) To incorporate into the model cost factors such as expressway toll other than required time, in order to understand the effect of varying the expressway tolls on traffic demand.

2) To develop a model considering the competitiveness of other transport modes such as rail, bus, airplane or ship both for passenger and freight. In order to cope with the assignment of the development of the model, it is necessary to collect the data of other transport modes such as the historical change of the multi-modal networks.

REFERENCES

KAJIKAWA.S (1999) On the Relationship between Traffic Volume of Expressway and Recent Economic Trends, **Expressways and Automobile Vol.42, No.12**, Express Highway Research Foundation, Japan, 43-50.

SASAKI.K, SATO.T and KUNIHISA.S (1999) Macro Economic Effect of Road Transport Policies: Empirical Analysis for Japan, **Interdisciplinary Information Sciences, Vol.5, No.1**, Tohoku University, Japan, 45-54.