RE-EVALUATION OF URBAN RAIL

The Case for Urban Rail Projects in terms of Energy Consumption, Environmental Protection and the Preservation of Human Life as seen in Three Major Metropolitan Areas of Japan

Akira NEHASHI
Manager, 2nd Construction Dept
Tokyo Branch Office
Japan Railway Construction
Public Corporation

Minema IKOMA
Chief, Survey Section Planning Dept
Kanto Branch Office
Japan Railway Construction
Public Corporation

Yosihiro AKIYAMA
Director
Japan Railway Technical Service
Tokyo-Japan

INTRODUCTION

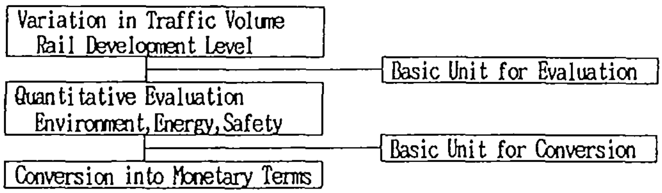
Railways are highly regarded compared with other means of transportation from the points of view of safety, high speed, large capacity, energy conservation, and environment. Of these, with regard to high speed and large capacity, these have been quantitatively evaluated in the form of external economic effect, but concerning safety, energy conservation, and environment, they have been evaluated only conceptually and qualitatively.

This paper, in view of the fact that the features of railways are demonstrated most conspicuously in safety, energy conservation, and environmental protection, presents a quantitative re-evaluation of railways in metropolitan areas (urban rail) in succession to the study on Shinkansen (intercity rail) made by the authors on the occasion of the Fifth Conference in Yokohama.

The transport facilities which are the objects of evaluation are railways (high-speed railways and streetcars), buses, commercial passenger cars (limousines, taxis), and private passenger cars. Since urban rail is the object of evaluation, in this case, only passenger transportation will be considered, with freight transportation outside the scope of study.

In concrete terms, based on the traffic volumes according to differences in the development levels of urban rail (density of rail network) in the three major metropolitan areas of Japan (Tokyo, Nagoya, and Osaka), it is checked how the indices of environment, energy, and safety (respect for human life) will vary according to the development level. As case studies, the three levels of rail development with (1) no railway available with all transportation relying on automobiles, (2) rail transportation at the present level, and (3) all railways planned in the individual areas developed, are assumed, and trial calculations are made as to how the variation in traffic volume due to differences in level will affect the various emissions of air pollutants, energy quantities required in terms oil, and how much the fatalities and injuries due to traffic accidents will vary. (The approximate flow of the abovementioned trial calculations is shown in Fig. 1.)

Fig.1 Flow of Urban Transportation Evaluation



1. TRANSPORTATION SITUATIONS IN THREE MAJOR METROPOLITAN AREAS OF JAPAN

1.1. Location of Three Major Metropolitan Areas

In Japan, there are three major metropolitan areas, the Capital Area centered on Tokyo, the Keihanshin Area centered on Osaka, and the Chukyo Area centered on Nagoya, and these are called the Three Major Metropolitan Areas. The three areas are all on the Pacific Ocean side, roughly in the central part of Japan, and the Tokaido Shinkansen has been built to interconnect these areas.

1.2. Population and Sizes of Metropolitan Areas

The areas and populations of the three major metropolitan areas are 6,400 km , 27 million in the Capital Area, 3,900 km , 7 million in the Chukyo Area, and 5,400 km , 15 million in the Keihanshin Area. The total population of these areas amounts to 50 million, to make up more than 40% of the population of Japan.

1.3. States of Rail Development and Traffic Volumes

As of 1985, there were in the three metropolitan areas 21 companies in the Capital Area with 85 lines and 1,980 km of operating length, 6 companies in the Chukyo Area with 39 lines and 850 km, and 19 companies in the Keihanshin Area with 70 lines and 1,350 km. Of the lines in operation, approximately 80% (ratio to line length) in the Capital and Keihanshin Areas, and approximately 60% in the Chukyo Area are double-track or more.

As for traffic volumes, they were 18.7 billion, 3.7 billion, and 8.9 billion for the Capital, Chukyo, and Keihanshin Areas, respectively, according to total transportation records for 1985. These figures roughly agree with the population ratios of the areas, and it may be considered that the traffic volumes of the three areas are approximately at the same levels as the population ratios. Seen by type of transportation modes, in the Capital Area, rail transportation was overwhelmingly large at 59%, and this was followed by private passenger cars at 25%. The trend in the Keihanshin Area was the same with rail 52% and private passenger cars 31%. In the Chukyo Area, however, the ratios were reversed with private passenger cars 59% and rail 26%. (Table 1)

2. MODAL DEMAND FORECAST

2.1. Method

The technique consists of calculating the relationships of rail development level and modal demand share from the present level of rail development and actual share, and obtaining the share at the forecast rail development level to determine variations in the numbers of passengers carried by individual transportation modes. (The approximate flow is shown in Fig.2)

2.2. Regression Equation

Indices to indicate rail development level are set up to obtain a regression equation for the level of rail development and the modal demand share. In this case, it was decided to adopt the value obtained by dividing kilometers of single-track railway (high-speed railway) by area of urban transportation region.

In regression, the index values and share percentages of the three metropolitan areas in 1965, 1975, and 1985 were used, and firstly, regarding railways, the solutions were sought by logarithmic regression, rail plus private passenger cars and rail plus commercial passenger cars by index regression, while for buses the remainder after calculation of the shares of other transportation modes was taken.

2.3. Development Level of Railway Considered for Evaluation

Next, to make trial calculations of how the indices of environment, energy, and safety (respect for human life) vary according to differences in the rail development level, a hypothetical level of rail development is set up.

In Japan, the Transport Policy Council (TPC), which is an advisory body to the Minister of Transport, decides on a railway line to be developed by the targeted year as a Transport Policy Council Recommended Line, and after adjustments to the developing principle and fund procurement, the line is constructed and put into service. Recommendations have been made for the transportation networks of the Capital, Chukyo, and Keihanshin Areas also (although the advisory body was a different one for Chukyo). For the Capital Area, a recommendation was made in 1985 for development to be carried out with the year 2000 as the target. (Table 2)

Table 1 Passenger in Three Major Metropolitan Areas (1985)
[Unit: million passengers , % shares in ( )]

	Capital Area	Chukyo Area	Keihanshin Area
Rail	10,960 (59)	1,003 (26)	4,673 (52)
Bus	2,116 (11)	421 (11)	1,039 (13)
Commercial Car	892 (5)	144 (4)	445 (5)
Private Car	4,731 (25)	2,213 (59)	2,745 (31)
Total	18,700 (100)	3,781 (100)	8,903 (100)

Fig. 2 Flow of Modal Demand Forecast

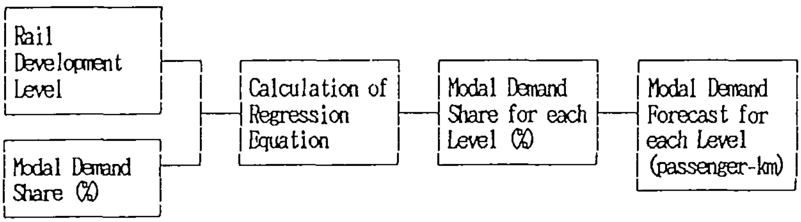


Fig. 3 Relationships of Development Level (Single-track Length/Area) and Shares of Transportation Modes

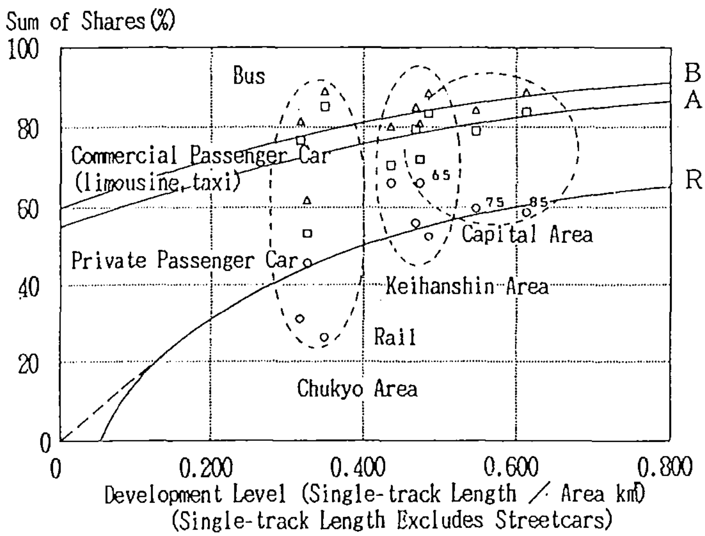


Table 2 Forecast of Future Transportation in Capital Area

Target Year	Population (thousand)	Area (km²)	Single-track length (km)	Volume of Transportation (million passengers)
2000	29,300	6,407	4,887	25,400

The three cases of no railway, present state of development, and development to the maximum limit are hypothesized here as the levels of rail development to be the objects of evaluation.

Level 1: Hypothetical case of no railway with all transportation by automobile

Level 2: Present level of development

Level 3: All planned lines developed

2.4. Estimate of Ridership According to Rail Development Level

The volumes transported according to the various transportation modes at present and at the target year of development are obtained by determining the modal demand shares at the hypothesized levels by the regression equation of development level and modal demand shares.

2.4.1. Forecast of Total Ridership

Calculations were made by primary regression from the trend curves of total riderships during the past 15 years, and in the year 2000 a total ridership of approximately 25.4 billion passengers is estimated for the Capital Area.

2.4.2. Estimate of Modal Demand Ridership

The modal demand riderships at the three levels of development in 1985 and 2000 were obtained from the respective shares based on the total ridership of 1985, the forecast total ridership of 2000, and the development level index and modal demand share regression curve. It was assumed in this case that there would be no induced ridership due to difference in developing level.

Further, the average distance transported per passenger according to transportation modes from 1982 to 1986 was determined, and assuming that this average would not change even in 2000 and even when the shares differ, the modal demand riderships previously obtained were multiplied by this average to calculate the estimated passenger-km of the individual transportation modes for each development level. (Table 3,4)

Table 3 Average Distance Hauled per passenger in Capital Area('82~'86)
(km / passenger)

Rail	Bus	Commercial Car	Private Car
13.0	3.2	5.4	17.8

Table 4 Estimated Passenger-km by Case in Capital Area
[million passenger-km]

Rail	Development Level	Rail	Bus	Commercial Car	Private Car
FY 1985	Non Rail	0	23,700	5,100	182,600
	Present Level	142,300	6,700	4,800	84,300
FY 2000	Present Level	199,900	9,600	7,500	99,100
	Planned Lines Developped	218,300	7,100	6,800	90,100

Note: ・Average distanse hauled per passenger is considerd to be constant in every case

Table 5 Atmospheric Pollutant Emission Units
(ton / million passenger-km)

	CO2 (×1,000)	NOx	SOx	Remark
Rail	46	1,790	110	Power Generation
Bus	675	5,040	1,440	Fuel
Commercial Car	3,670	4,960	410	Fuel
Private Car	1,230	2,570	210	Fuel

3. BASIC UNITS FOR EVALUATION

As basic units for evaluation of effects on environment, energy, and safety of the differences in rail development levels, the effects on the environment (atmospheric pollution), energy consumption, and rate of fatalities due to accidents (safety) per unit traffic volume (passenger-km) of the various transportation modes were determined. Here, carbon dioxide, nitrogen oxides, and sulfur oxides were selected as items concerning environment.

Table 6 Energy Consumption Units

(kcal／passenger-km)

Rail	100Kcal
Bus	174Kcal
Passenger Car	507Kcal

Table 7 Casualty Rate by Transportation Modes

(National Total Record of 6 Years)

Transpor-tation Modes	Traffic Vol. (A) (billion pas.-km)	Fatalities (B) (person)	Injuries (C) (person)	Ratio (B)/(A)	Ratio (C)/(A)
Rail	1,656	88	176	0.53	1.1
Bus	425	348	25,352	8.2	597
Commercial	95	1,773	129,568	187	13,640
Private	2,334	27,300	1999,325	117	8,570

Note: 1. Record of 6-year period, 1982-87, for rail
2. Record of 6-year period, 1983-88, for automobile

4. QUANTITATIVE EVALUATIONS OF ENVIRONMENT, ENERGY, AND SAFETY

4.1. Cases Evaluated

Trial Calculation 1: Comparison of present traffic volume all transported by automobile with traffic volume according to actual modal share of transportation

Trial Calculation 2: Comparison of all planned lines constructed by 2000 with if fixed at present rail development level.

4.2. Results of Quantitative Evaluation of Environment, Energy, Safety

(Table 8-1,8-2)

4.3. Results of Quantitative Evaluations for Three Metropolitan Areas

Quantitative evaluations were next made on the three major metropolitan areas as a whole.

Due to the existence of urban rail the totals for the three major metropolitan areas show reductions of 18 million tons for CO_2, 12,000 tons for NOx and 5,000 tons for SOx, while energy in terms of oil equivalent is conserved by 5.5 billion liters (one month's consumption of total energy for transportation in Japan), while in the aspect of safety 1,590 fatalities and 117,000 injuries are prevented annually.

And if the urban rail development plans of Japan targeted for the year 2000 are completed, there will similarly be alleviation of environmental loads of 2.3 million tons of CO_2, 1,000 tons of NOx, and 700 tons of SOx. Energy savings annually of 600 million liters in terms of crude oil (0.1 month's consumption of energy for all transportation of Japan) will also be made, while with regard to safety, 230 fatalities and 14,100 injuries will be prevented annually. (Table 9)

Table 9 Results of Quantitative Evaluations of Individual Cases in Three Major Metropolitan Areas

Case	Environment (1,000 ton)			Energy (10^9 liters)	Safety (person)	
	CO_2	NOx	SOx		Fatality	Injury
Trial Calculation 1	17,850	12.2	5.2	5.52	1,590	117,000
Trial Calculation 2	− 2,270	− 1.0	− 0.7	− 0.6	− 230	−14,100
Present figure(1985)	25,000	92.2	8.1	11.9	2,760	153,000

Table 8-1 Quantitative Evaluation Results
(Trial Calculation 1: Significance of Urban Rail)

Capital Area		Rail	Bus	Commercial Car	Private Car	Total	Increase Decrease
1,000 passenger/day million passenger-km /year		−30,027 − 142,300	14,740 17,000	164 300	15,123 98,300	—— ——	—— ——
Environment	CO_2 1,000ton NOx ton SOx ton	− 660 −25,610 − 1,420	1,150 8,500 2,380	110 150 12	12,060 25,560 1,970	12,700 8,600 2,940	96% 16 65
Energy	Consumption (billion Kcal) Oil Equivalent (billion liters)	− 142,300 −15.1	29,580 3.1	1,520 0.2	498,400 53.0	387,000 41.2	 64
Safety	Fatality (person) Injury (person)	− 8 −16	14 1,015	6 409	1,150 84,214	1,160 85,620	107 92

Table 8-2 Quantitative Evaluation Results
(Trial Calculation 2: Significance of Completing Planned Lines)

Capital Area		Rail	Bus	Commercial Car	Private Car	Total	Increase Decrease
1,000 passenger/day million passenger-km /year		3,890 18,400	− 2,164 − 2,500	− 356 − 700	− 1,370 − 9,000	—— ——	—— ——
Environment	CO_2 1,000ton NOx ton SOx ton	80 3,310 180	− 170 − 1,250 − 350	− 260 − 350 −30	− 1,100 − 2,340 − 180	− 1,450 − 630 − 380	−9% −1 −6
Energy	Consumption (billion Kcal) Oil Equivalent (billion liters)	18,400 2.0	− 4,350 − 0.5	− 3,550 − 0.4	−45,630 − 4.9	−35,100 − 3.8	 −5
Safety	Fatality (person) Injury (person)	1 2	− 2 − 149	−13 − 954	− 105 − 7,710	− 120 − 8,810	−9 −9

Note 1, Oil equivalent 9,400Kcal/liter
2. 'Increase or Decrease' means increase or decrease from present level

5. CALCULATION OF SOCIAL COST

5.1. Cost of Environmental Pollution

According to a report by the Worldwatch Institute of the United States in 1988, in order to eradicate the environmental pollution (greenhouse effect, desertification, ozone layer destruction, extinction of biological species) presently proceeding on a global scale while further going ahead with sustained development hereafter, it will be necessary to make an enormous investment of 20 trillion yen (150 billion dollars) annually over the next 10 years.

Although the cost of restoring the environment will not necessarily be proportionate to energy consumption, estimating here the environment restoration cost due to difference in rail development level from the ratio of energy consumption amounts, for example, in Trial Calculation 1 (comparison of assumption of automobile transportation only with actual modal share of transportation), it will be 15 billion yen annually. The quantitative causes of atmospheric pollution are not taken into consideration in this case. As for the amount calculated, it is felt to be slightly too small from the standpoint of a monetary image.

5.2. Amount of Energy Loss

The energy loss, in Trial Calculation 1, for example, is 5.52 billion liters annually as an equvalent in oil. Although oil prices are not constant and fluctuate greatly, if the evaluation here is calculated by the 1985 imported oil price of 42.37 yen/liter, the loss will amount to 234 billion yen. This means that savings of this amount are made every year due to the existence of urban rail. In Trial Calculation 2, it is shown that with completion of the plans for rail development there will be savings corresponding to 25 billion yen annually.

5.3. Amount of Human Loss

The evaluation of safety will be made from the point of view of loss in human resources.

Human loss is expressed in terms of 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 should not usually be valued in monetary terms alone. However, estimating a person's lifetime wages at about 200 million yen (at 1985 prices), and the average age for accident fatalities to be 35.6 years old, the loss of a human life is equivalent to about 180 million yen. The lifetime wages of a person from 20 to 60 years of age are assumed to be linear in progression.

For example, in Trial Calculation 1, since fatalities in accidents amount to 1,590 persons annually, the human losses amount to

286 billion yen a year. In Trial Calculation 2, this would be 41 billion yen for 230 persons.

Note that these figures for production loss do not include persons who are injured. When various irreplaceable social, domestic, and psychological losses apart from wages are considered, the losses in connection with the preservation of human life must be evaluated as being far greater.

5.4. Summarization of Social Cost

Converting the three factors of environment, energy and safety into monetary terms, the results below are obtained in trial calculations of the total social costs in the three major metropolitan areas of Japan.

The present level of rail development may be considered to be producing 534 billion yen annually, and if all development plans up to the year 2000 were to be completed, there would be further savings in social costs of as much as 68 billion yen annually.

Table 10 Basic Units for Conversion into Monetary Terms

Item	Basic Units
Environment	Costs of eliminating environmental pollution and promoting sustained development, 20 trillion yen /7,426 billion liters
Energy	Crude oil import price 42.4 yen /liter
Safety	Lost wages due to accident fatality, 180 million yen /person

Table 11 Increase or Decrease in Social Cost by Case
(Total for Three Major Metropolitan Areas)
[billion yen/year]

Case	Environment	Energy	Safety	Total
Trial Calculation 1	15	234	285	534
Trial Calculation 2	−2	−25	−41	−68

Trial Calculation 1: Comparison of present traffic volume all transported by automobile with traffic volume according to actual modal share of transportation

Trial Calculation 2: Comparison of all planned lines constructed by 2000 with if fixed at present rail development level

CONCLUSION

Urban rail has been highly regarded in view of its high-speed, mass transit properties, and its regularity of runs. This paper has reported on the trial calculations made for quantitative evaluations of urban rail in the aspects of environment, energy, and safety. As a result, assuming that there were no railway, it was found that there would be a loss of 500 billion yen annually in social costs in the three major metropolitan areas of Japan alone. Trial calculations from the transportation conditions of the three major metropolitan areas of Japan may not necessarily be directly applicable to various cities of the world where municipal functions and topographical-geographical conditions differ. However, it is hoped that with this as the impetus, discussions related to evaluation of transportation modes from the aspects of environment, energy, and safety will become more active, and when considering the introduction and construction of railways, a means of mass public transportation, in new urban development and urban improvement throughout the world, transportation projects friendly to the environment will be promoted in various countries giving thorough consideration to their significant effects with regard to environment, energy, and safety.

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