Effects of High-Speed Transportation Systems on Environmental Improvement in Japan

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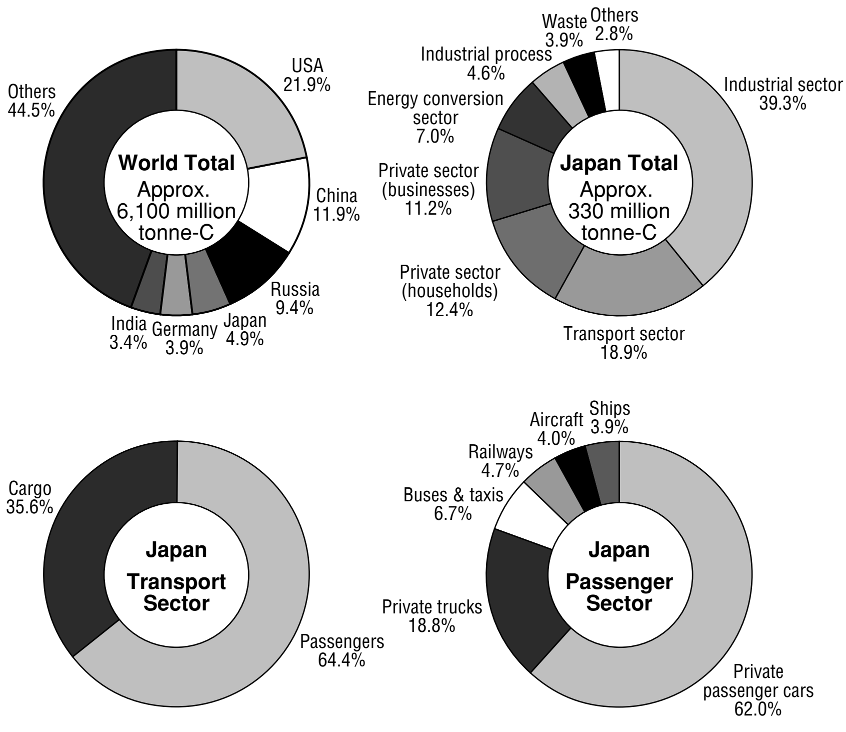
In Japan, the use of motor vehicles still shows no signs of decreasing and road traffic continues to rise in terms of both urban and inter-city transport. As a result, a reduction in carbon dioxide (CO_2) emissions by the transport sector is far from being achieved. Similarly, local air pollution caused by nitrogen oxides (NOx) and suspended particulate matter (SPM) is still common and many urban areas fail to meet government air quality standards. Meanwhile, public pressure for environmental improvement has intensified in recent years. The Japanese government agreed to reduce emissions of gases causing global warming at the UN Convention on Climate Change (COP3) held in Kyoto in December 1997. In July and August 1998, suits were filed against the government and highway authorities in Osaka and Kawasaki, respectively, alleging their liability for local air pollution caused by exhaust gases. Clearly, drastic and urgent actions are expected from the transport sector toward environmental improvement, especially in the management of urban and inter-city transport.

This article reviews major environmental issues facing Japan and analyzes the current status of environmental improvement policies undertaken by the Ministry of Transport (MOT), along with technology to control pollution at source. In particular, evaluation of various environmental parameters is becoming important, especially analytical systems to quantify the effects of policies and programmes. Major issues related to such quantitative assessment are identified and analyzed. Finally, we describe a recently developed analytical framework to evaluate the effects of environmental improvement measures on inter-city transport, including upgrading of rail service levels, increasing charges for using automobiles, and promoting low-pollution vehicles. The evaluation results for various programmes are presented.

Global Warming and Local Air Pollution

Figure 1 shows the breakdown of CO_2 emissions by country in 1992. Japan ranks fourth in absolute amount of CO_2 emissions. Per capita emissions are around 50% of the USA and Canada, at the same level as the UK and Italy, and four times the level of China. The ratio of emissions to GNP is equivalent to that of Italy, 50% that of the USA, Canada, and the UK, and 5% that of China. By industry, the transport sector accounts for 18.9% of the total CO_2 emissions in Japan, and is the key to effective reduction of emissions. Within the transport sector, passenger transport produces the dominant (64.4%) share of emissions, of which automobile transport accounts for 87.5%. The share of emissions by the transport sector has been rising each year, explaining why CO_2 emissions by the transport sector grew 90% between 1973 and 1994, in contrast to the 20% increase by all sectors. Table 1 shows the environmental impacts predicted by the Environment Agency on Japan caused by doubling the present CO_2 concentration; the impacts are extensive. Table 2 summarizes the impacts of local air pollutants on people. The NOx level has been gradually declining, but it is still higher in major urban areas than exhaust emission standards. In 1991, the carbon monoxide (CO) levels at all air quality monitoring stations throughout Japan met the emission standards. The level of sulphur oxides (SOx) declined by 82.4% between 1970 and 1989, due to reduction of the sulphur content of fuels, wider use of desulphurization technology, and improved fuel efficiency. Progress with

Figure 1 National CO_2 Emissions in 1992



SPMs is rather slow; in 1991, only 50% of air quality monitoring stations and just 30% of exhaust gas monitoring stations met the environmental standards. Diesel vehicles are estimated to produce 20% to 40% of SPM emissions.

CO_2 Emissions by The Transport Sector and Traffic Demand Trends

Despite these apparent improvements, passenger traffic in the transport sector has been shifting continuously from energy-efficient railways to energy-inefficient systems such as the private motor vehicles. Figure 2 shows the changes in modal share of inter-city passenger transport (passenger-km) between 1955 and 1994. Motor vehicles have increased their share at an accelerating rate since 1965, from 32% to 67%. For trips of 300 km or more, air transport has gained a considerable share due to growth of personal income and the increase in the number of local airports.

As shown in Fig. 3, the use of motor vehicles in urban transport has risen rapidly. Clearly, motor vehicles have gained in popularity for commuting and private trips. Table 3 shows that energy consumption per passenger-km by road transport in urban areas during rush hours is about 23 times that of railways, not to mention the resultant chronic congestion and air pollution. In contrast, Japanese railways mainly use electricity for power, which causes less air pollution.

There is now a serious need to reduce the environmental impacts of the transport sector by developing a well-coordinated system that combines different modes according to their advantages. For example, the railway can carry large numbers of people over short to medium distances with high energy efficiency, air has the overwhelming advantage of speed over long distances, and roads are convenient for door-to-door continuity.

Table 1 Impact on Japan of Doubling of Atmospheric CO_2 Levels

Item	Description
Air temperature	Mean annual temperature will rise 1°–2.5°C.
Precipitation	Mean annual precipitation will change between -5% and +10%.
Sea level	Levels will rise 10–20 cm in the Sea of Japan and 15 cm in the Pacific.
Extinction of some species	Warming will force some animals and plants to move northward or to highland, but lack of habitat due to topography, urbanization and other factors may cause extinction.
Agriculture	• Rice yield will increase in northern Japan and decrease in west Japan. • Due to low self-sufficiency in food supply, Japan's food supply and demand will be affected by changes in production volume of exporting countries. • Temperature rise may cause magnesium and other minerals in rice to decrease, resulting in deterioration of taste.
Fishery	The southern limit of the range of salmon will move northward.
Hydrology and water resources	Increase in rainfall instead of snow and early snow melting will increase river flows in winter and decrease them in spring, creating a risk of water shortages.
Coastal area	The rise in sea levels will erode coasts at an accelerated rate. Many sand beaches in resort areas will disappear.
Tourism and recreation	Earlier snow melting will shorten the ski season and affect tourism severely. Also, coastal erosion will wash away many beach resorts.
Health	• Health disturbances caused by heat, such as heat stress and heat stroke, will increase, particularly among the elderly. • Animal-vector diseases, such as malaria and dengue fever, will increase. • The rise in maximum daily temperature will increase the death risk, particularly among the elderly. Circulatory ailments will become the primary cause of death. • NOx emitted from automobiles and factories will react with UV to produce photochemical smog which causes acute and chronic health damage, including respiratory diseases.

Table 2 Health Impacts of Air Pollutants

Item	Description
Nitrogen dioxide (NO_2)	Adverse effect on respiratory organs at high concentrations
Carbon monoxide (CO)	Bonds with hemoglobin in blood to disturb oxygen transport
Sulfur dioxide (SO_2)	Damages respiratory organs, causing asthma (the Yokkaichi asthma)
Particulates (SPM)	Builds up in lungs and trachea

Table 3 Energy Consumption of Different Transport Modes

Energy consumption	Rail	Auto	Bus	Air
Per passenger-km	100	534	168	—
Per passenger (between Tokyo and Osaka)	100	461	101	300
Per passenger in Tokyo Metropolitan Region (during peak hours)	100	2,343	150	—
The figures are indexed to rail = 100.				

Figure 2 Modal Share of Inter-city Passenger Transport (passenger-km)

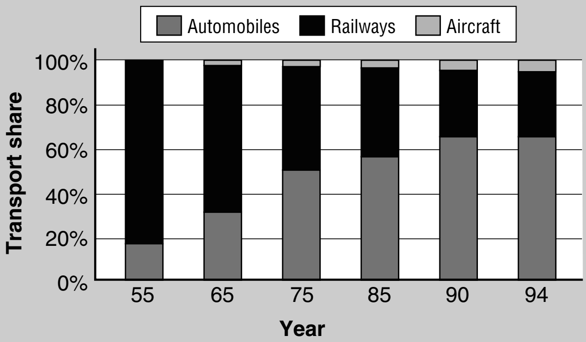
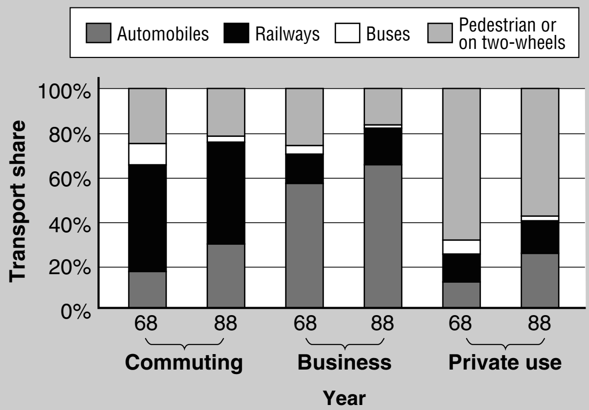


Figure 3 Modal Share in Metropolitan Tokyo



Environmental Improvement Policies in Transport Sector

The Japanese MOT has been studying and developing a package of both technical and institutional policies to address the issue of global warming (Table 4). The strategy with the highest priority is emission control at source for motor vehicles. However, the importance of other policy measures, including diversion of traffic to energy-efficient systems, control of motor vehicle use by area, date and/or time zone, public campaigns about the need to reduce CO_2 emissions, and technological cooperation with other countries, are all recognized. More precisely, short- and medium-term measures up to 2010 include changing the automobile tax system, promoting the 'eco-drive' concept, constructing and upgrading public transport systems, promoting their use, and streamlining distribution systems. These measures will evolve into long-term measures, including development of zero-emission vehicles (ZEV).

Recently, a variety of R&D efforts are underway to control emissions at source. New technology is being developed in the following main areas: (1) improving engine thermal efficiency; (2) reducing acceleration resistance by cutting vehicle weight; (3) reducing rolling resistance; (4) reducing energy loss in drive system, such as transmission; and (5) modifying engine design to burn alternative fuels. Table 5 compares the major features of new motor vehicles powered by conventional and alternative fuels. Compared with present vehicles, cars powered by fuel cells, electricity and natural gas have excellent prospects for reducing CO_2 emissions, but they still have to overcome problems of limited driving range.

The railway industry is also making extensive efforts to become more environment friendly. For example, since 1992, JR East has been setting the goals shown in Table 6. In the fields of energy saving and reduction of CO_2 emissions, the major focus is on upgrading railcar design and performance as well as on power generation systems. Weight reduction, use of regenerative braking, and introduction of variable voltage variable frequency (VVVF) circuits are major parts of the effort to achieve higher energy efficiency. For example, JR East's latest Series 209 EMU has been improved as shown in Table 7 to achieve a 50% reduction in energy consumption compared to its Series 103 predecessor. R&D into power generation involves development of more efficient and cleaner energy sources. In addition, state-of-the art technologies are being developed, such as waste heat recycling and commercialization of solar power generation. The 16 leading private railway companies are increasingly using energy-saving vehicles (Table 8).

Assessing Effects of Environmental Improvement Measures

Generally, quantitative analysis conducted to assess the effects of environmental improvement measures by the transport sector is designed to determine costs and benefits. Two indicators: physical, such as emitted amount of pollutant, and economic, such as damage to the national economy caused by environmental degradation, are used. However, a major problem is how to establish reliable and agreed base values for pollutant emissions and social costs. Comparison of base values currently used in Japan shows considerable variation among published data; the difference between the values is as large as 200% for CO_2, 400% for NOx, 300% for SOx, and 1000% for CO (Table 9). This is caused by a number of factors, including differences in vehicle age, model, and fuel in different studies, as well as differences in statistical analysis methods. In any case, the fact remains that the most vital and important set of data for policymaking are not available.

A similar situation exists in quantifying the social costs of air pollution. Although much research has been conducted in the USA and Europe, there is no agreed uniform method to measure social costs. Moreover, the measurement conditions vary considerably between countries, resulting in great variation of social costs. Similarly, there are practically no useful data on social costs available in Japan, especially no measured data related to the social costs of global warming, which can be used in the transport sector. To address this shortcoming, we applied the contingent valuation method to measure the social cost defined as the amount that Japanese people would be willing to pay for government policy measures to counter both the positive and negative effects on the Japanese environment and society (Table 1), caused by a rise in air temperature of 1° to 2.5°C resulting from a doubling in the level of atmospheric CO_2. A questionnaire prepared according to the US National Oceanic and Atmospheric Administration (NOAA) guidelines was used to survey 1620 people in Tokyo, Nagoya, Osaka, Sendai, Okayama, and Kumamoto. The survey showed that respondents would only pay ¥8235 per year to prevent global warming. This figure was then used to determine the social cost per tonne-carbon, which came to ¥8320/t-C.

Although we hope that base value emissions will soon be made more precise and unified, current quantitative analysis methods and data must allow for some different possibilities, and failure to do so could result in incorrect policy decisions.

Table 4 Global Warming Countermeasures Proposed by Ministry of Transport

	Short- and medium-term policies (up to around 2010)
Technological	1 Development and proliferation of fuel-saving cars • Accelerate development of Gasoline Direct Injection engine, lean-burn engine and diesel-powered cars. • Develop and promote use of hybrid and electric cars. 2 Utilization of traffic demand management techniques 3 Urban development to encourage use of public transport systems • Plan and develop effective use of urban bus services. • Accelerate development of rail and light rail transport systems. • Enhance nodes between different transport systems. 4 Streamlining of physical distribution systems • Improve efficiency of truck transport by using Intelligent Transport Systems (communal transport, optimum vehicle allocation, and computer-guided optimum route selection). • Promote modal shift to rail and marine transport. • Reduce on-land transport by constructing international container ports at strategic locations.
Institutional	1 Modification of auto tax system • Reclassify automobile tax rates on basis of fuel economy, instead of displacement, to encourage purchase of fuel-saving cars. 2 Expansion of subsidy system to encourage construction of rail and LRT systems
Other	1 Promotion of 'eco-drive' concept • Stop engine while not moving. • Drive at economic speeds on highways. • Encourage car pools. 2 Promotion of international cooperation • Assist developing countries in development of urban transportation systems and improvement of fuel economy. 3 Strengthening of environmental monitoring system focusing on greenhouse gases 4 Promotion of resource recycling

Table 5 Comparison of Major Features of Alternative-Fuel Cars

Vehicle type		Nitrogen oxides	Hydrocarbons and carbon monoxide	Solid particulate matter	Carbon dioxide	Power	Cruising range
Gasoline		— Baseline Index —					1.0
Diesel		Much worse	Same	Much worse	Better	Worse	1.2
Methanol	Otto engine	Same	Same	Same	Same	Same	0.5
	Diesel engine	Worse	Same	Same	Same	Worse	0.6
Natural gas (CNG)		Same	Worse	Same	Better	Worse	0.2
Electric		Much better	Much better	Much better	Better	Much worse	0.1
Fuel cell/electric		Much better	Much better	Much better	Better	Much worse	0.1

1. The cruising range is expressed as an index where gasoline cars = 1.0 (same tank capacity).
2. The CO_2 emissions include the fuel production and consumption stages.
3. CO_2 for methanol cars is produced when methanol is produced from natural gas.

Table 6 JR East Environmental Improvement Measures (at 1996)

Item	Target
Energy/CO_2	To reduce energy consumption per unit traffic volume related to train operation by 10% in or before FY2001. Also to reduce CO_2 emissions from own thermal power stations by 10%.
NOx	To reduce NOx emissions from own thermal power stations by 40% in or before FY2001.
Destruction of ozone layer	To convert 30% of air-conditioning equipment using designated freon gases, to the non-freon type by FY2001.
Resource recycling	To increase the recycle rate of wastes produced from construction work and factories to 70% and that of wastes produced from stations and trains to 30% by FY2001.
Resource saving	To increase percentage of recycled paper in office paper consumption to 90% and to reduce consumption of water resources by 5% in or before FY2001.
Natural environment	To plant 30,000 trees each year.
Noise and vibration	To reduce noise in wayside areas (those designated as 'areas equivalent to densely populated residential areas') of the Tohoku/Joetsu Shinkansen Lines to 75 dB or less.
To review reduction targets in consideration of future research and technological advancement (FY1984 as baseline year).	

Table 7 JR East Equipment Performance Upgrades

Model	103 Series	209 Series
Year of manufacture	1965–83	1991–
Weight	36.3 t/unit	25.0 t/unit
Main circuit	Rheostatic control system	VVVF inverter control system
Braking system	Dynamic brake/ electromagnetic straight air brake	Regenerative brake/ electric command air brake, unit brake system
Regeneration rate		Approx.35%
Energy consumption	100 (standard)	47

Table 8 Energy-Efficient EMUs Introduced by Large Private Railway Companies

As of March 1998	No. of units	Percentage share of total
Lightweight cars	3,750	22.3%
Regenerative brake cars	10,133	60.4%
Chopper control cars	6,742	40.2%
VVVF cars	3,182	18.9%

Policy Analysis System LETS

The Low Emission Transportation System Simulator (LETS) is designed primarily to assess the effects of environmental improvement measures for inter-city transport systems. It is based on the widely used demand forecast model with some customization, and examines the macro relationships between traffic demand and environmental impacts. The system programme runs on a PC and produces simulation results in 2 minutes. It measures the above effects by combining traffic data (passenger-km) obtained from the demand forecast model with base values for pollutant emissions and social costs. The result can be used to estimate user benefits that are consistent with the demand forecast.

Figure 4 shows the fundamental structure of LETS. The demand forecast sub-unit for inter-city transport analyzes demand changes caused by development of high-speed transport networks or increases/decreases in fares and taxes. Another sub-unit quantifies changes in pollutant emissions from different transport modes, the incidence of traffic accidents, etc. Multiplying traffic data (passenger-km) from the demand forecast sub-unit by emission base values for respective transport modes, gives the environmental pollution loads and other data. A third sub-unit measures changes in environmental pollution loads caused by development of high-speed transport systems in monetary terms to determine the external economic effects of such development. The use of monetary units allows various environmental pollutant loads (e.g., CO_2, NOx) to be treated uniformly as social costs that can then form the basis of cost/benefit analysis.

The traffic demand forecast sub-unit uses a four-stage estimation method based on three types of trip (business, tourism, other) and three transport modes includ-

Table 9 Comparison of Pollutant Emissions Base Values by Transport Mode

Pollutants	Automobiles	Rail	Air
CO_2 (g-C/passenger-km)	27 – 46	5.2	41 – 53
NOx (g/passenger-km)	0.26 – 1.0	0.30	0.47
SOx (g/passenger-km)	0.016 – 0.041	0.018	0.209
CO (g/passenger-km)	0.094 – 0.93		

ing air, rail, road (excluding bus).

Existing demand forecast models tend to underestimate environmental impacts because they fail to take induced traffic into account. To address this shortcoming, LETS estimates induced traffic by linking different models at various stages through accessibility variables. As a result, it can express induced traffic volumes and changes in selection of destinations due to reduced travel time caused by increased railway operating speeds. Moreover, LETS can analyze how traffic is affected by decreases in disposable income caused by fare increases. Figure 5 shows the concept of the induced demand generation process. The size of the circles represents traffic volume, and the changes in circle size show that traffic distribution patterns change with the improvement of transportation systems. In the diagram on the left, trips starting in zone O are divided equally between three destinations: A, B, and C. As improvement in the transport system reduces the travel time between zones O and A, more traffic is induced in zone O (shown by a black outer circle), leading to a significant increase in the number of trips to zone A. The increase in total traffic volume spills over to zone C, although the transport system from zone O to C has not been improved, but trips from zone O to zone B decrease because the transport to zone B is less convenient than the other two destinations.

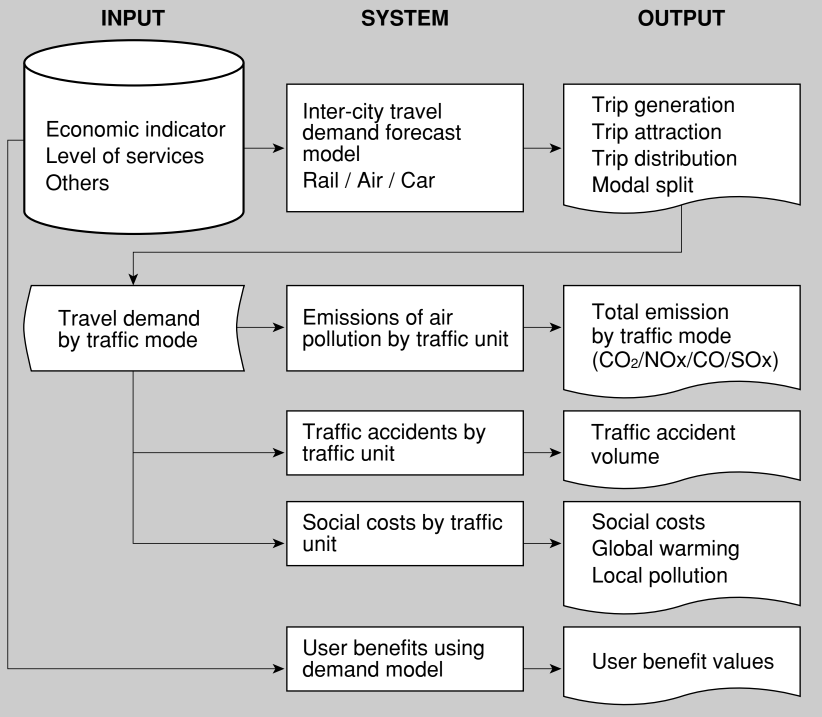
Analysis of Policy Measures and Effects

This section describes the LETS simulation results based on the Japanese transport networks shown in Fig. 6. The environmental improvement effects and socioeconomic impacts of various policy measures are compared assuming that GDP grows at an annual rate of 2% while the number of automobiles per household grows at an annual rate of 1%. Table 10 summarizes the analyzed policy options, option levels, and forecast results for 2010.

If no environmental improvement measures are taken under the assumed conditions, total traffic volume expressed as passenger-km will grow by 47% between 1990 and 2010, and generated traffic volume will grow by 43% for the same period. The modal shares for the generated traffic volume are 67% for motor vehicles, 26% for rail, and 7% for air. Pollutant emissions will increase by 45% for CO_2, 47% for NOx, 42% for SOx and 49% for CO.

Table 10 also shows the rates of change in 2010 when improvement measures are taken. First, improvement of rail services to encourage a demand shift to rail, which causes relatively small environmental

Figure 4 LETS Components



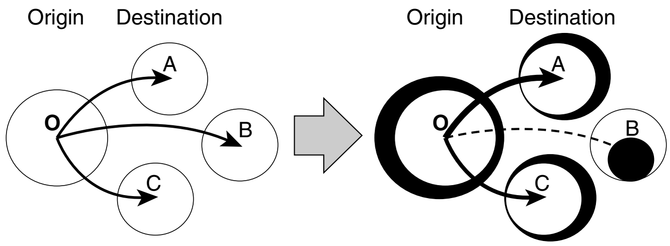
pollution loads, does not always contribute to environmental improvement because it induces additional demand at some improved service level (e.g., a significant increase in train speed). Nevertheless, pollutant emissions per trip are always reduced by a demand shift to rail. Generally, any economic measure such as increases in fares, tolls, taxes, etc., is most effective in producing environmental improvements, but the resultant increase in travel costs may negatively impact the utility (satisfaction) level of transport users to some extent.

However, it should be noted that LETS does not account for recycling of tax revenues. Consequently, effective investment of taxes generated by economic measures must be taken into account in the future.

Introduction of low-polluting cars is very effective in improving the environment, suggesting the need for purchase incentives.

Although it is well known that railways are clearly more environment friendly than other transport modes, their main advantage is their high transport efficiency, which should be the primary basis for deciding new construction.

Figure 5 Diagram Showing Induced Demand and Changing Traffic Distribution



The simulation results show that although strict policy measures (higher option levels) may not stabilize CO_2 emissions at the 1990 level, meaningful improvement can reasonably be expected by combination of pollution control measures at source (e.g., promotion of low-pollution cars) with effective measures to encourage demand shift to low-pollution transport modes such as rail.

A further analysis examined the effectiveness of two policy combinations: 1. Increasing operating speeds of inter-city lines along with increasing highway tolls; and 2. Increasing operating speeds of inter-city lines and creation of the carbon tax. The main purpose of this analysis is to find how to achieve environmental improvement without affecting the utility level of transport users. Figure 7 shows the relationship between social costs (related to global environment, local environment and traffic accidents) and

Table 10 Effect of Environmental Improvement Measures in 2010

Policy options/ option levels	Indicators for evaluation	Total passenger-km carried	CO_2 emissions	NOx emissions	Social cost of global warming ¥100 million/ year	Economic effect ¥100 million/ year
Increasing operating speeds of inter-regional rail service	Tokaido/Sanyo Shinkansen: 250 km/h Other lines: 150 km/h	+18%	-5%	+4%	-22	+17,155
	250 km/h for entire line	+56%	-3%	+15%	-15	+48,180
	300 km/h for entire line	+91%	-2%	+26%	-11	+81,030
Raising toll charges for all highways	Raise toll charge by 30%	-2%	-4%	-6%	-18	–1,825
	Raise toll charge by 50%	-3%	-6%	-10%	-29	–2,920
	Raise toll charge by 100%	-5%	-10%	-17%	-58	–8,030
Imposing fuel tax	Raise fuel price by 30%	-3%	-6%	-5%	-29	–2,555
	Raise fuel price by 50%	-5%	-8%	-7%	-47	–4,015
	Raise fuel price by 100%	-8%	-13%	-14%	-88	–8,030
Developing of low-pollution cars	Increase energy efficiency by 30%	—	-25%	-34%	-117	—
	Increase energy efficiency by 50%	—	-42%	-56%	-193	—

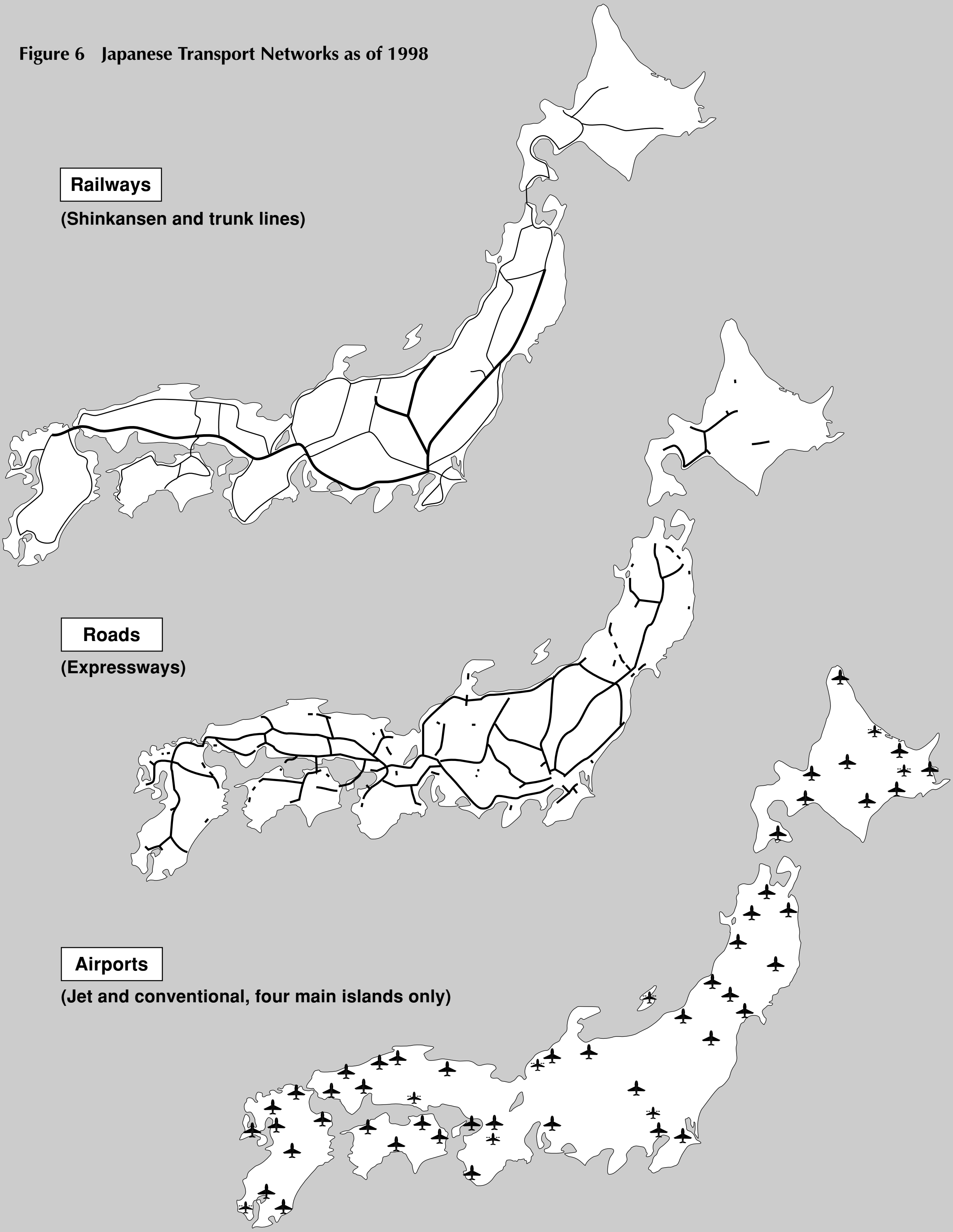
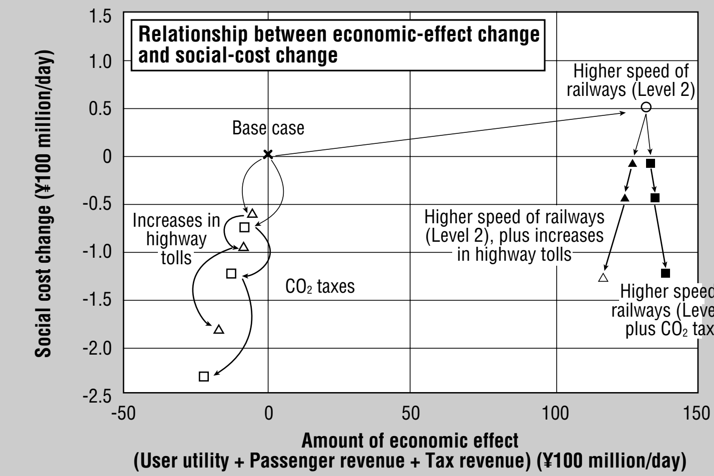


Figure 6 Japanese Transport Networks as of 1998

Sources: Ministry of Construction and Ministry & Transport economic effects. Introduction of the carbon tax on its own contributes to increased economic loss, but if it is combined with faster inter-city rail services, positive effects are produced. This clearly suggests that some options can achieve both environmental improvement and higher utility, depending upon taxation rates, traffic conditions, and other relevant factors.

The above analyses are useful for preliminary evaluation of various policy measures. However, at the same time, the relatively low precision of base values for pollutant emissions and social costs requires careful interpretation of the results. For example, the highest CO_2 base value for automobile emissions is 70% higher than the lowest value. When the former value is used to evaluate the economic effects of the carbon tax, users face a higher tax burden because the tax is imposed on the basis of the weight of emitted carbon. The reverse is true when the lowest base value is used. The difference has an impact on the results related to traffic demand, user benefits, and carbon tax revenues, thereby influencing policy options.

Figure 7 Economic Effects of Policy Combinations



Conclusion

As a concluding remark, we would like to point out major issues to be addressed for effective evaluation and implementation of policy options.

- Many policy measures in the transport sector tend to evoke trade-offs between improvement of convenience/economic development and environmental preservation/improvement. This is attributable primarily to lack of assessment of possible measures, and poor communication with affected parties. To ensure timely selection and implementation of effective measures, policy options (including scenarios) and evaluation results must be made available for broad-based public discussion.
- To encourage open and fruitful discussion, formal communication routes should be instituted between policymakers and the public.
- Since discussion of environmental policy tends to be dominated by intransigent positions based on different opinions, efforts should be made to develop a common viewpoint based on quantitative analysis using objective data. More precisely, base values for pollutant emissions and social costs should be unified through research and extensive field measurement, and a national consensus should be established on what values to use as the basis for discussion. Finally, forecasting models must be made more accurate. ■

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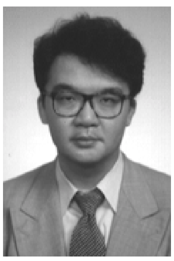

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