THE HIGH-SPEED INTER-CITY TRANSPORT SYSTEM IN JAPAN: PAST, PRESENT AND THE FUTURE

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SUMMARY

EXECUTIVE SUMMARY

With the advent of Shinkansen in 1964, a unique inter-city transport network emerged, in which high-speed railway and air transport developed simultaneously in Japan, giving rise to modal choice between them based on price and speed.

Looking ahead, the next generation of high-speed transport, the Maglev, is on the horizon. In order to capture the full impacts of Maglev technology, simulation analysis with a dynamic spatial nested logit model was conducted. From this we identify a significant opportunity for the Maglev Super-Express between Tokyo, Nagoya and Osaka, but net benefits would exceed net costs only when approximately 2-3% annual economic growth is achieved over the next 65 years in Japan. If such an economic condition is realised, the total air transport market would also continue to grow, despite strong competition from the Shinkansen/Maglev system.

Another point of interest is Maglev's impact on reducing global warming. CO_2 emissions from Maglev are about one-third of those from air transport. The introduction of the Maglev Super-Express in inter-city transport, however, also attracts passengers from Shinkansen which has five times lower CO_2 emission intensity than air transport. Indeed, our simulation analysis shows that total CO_2 emissions from high-speed inter-city transport increase when the Maglev Super-Express is introduced. The increase in total CO_2 emissions from electricity users, including the Maglev Super-Express, could be mitigated through efforts by the energy conversion sector to reduce the CO_2 content of the electric power supply, for instance, by increasing the use of nuclear energy. Further research on assessing the possible impact of capacity constraint on the existing network, not considered in this paper, would facilitate deeper understanding of future high-speed intercity transport systems.

1. INTRODUCTION

The increasing value of time in modern society has brought high-speed railway and air transport to the forefront of today's inter-city transport. With the advent of Shinkansen in 1964, Japan has unveiled the significant potential of high-speed railways in inter-city travel. The ICE in 1991 and TGV in 1993 have opened a new era for Europe, and at the start of the 21st century South Korea, followed by China, has introduced their system. This year, the United States' President (USA) has announced his vision for high-speed railways.

Unlike in the USA, where air transport has long stood as the dominant inter-city transport mode, air transport in Japan developed side-by-side with Shinkansen. Liberalization and infrastructure development have helped Japan to establish an extensive network for the air transport market, filling the gap in market segments that Shinkansen cannot fill. The two different modes of transport, high-speed rail and air transport, have provided Japan with a modern inter-city transport system with the unique feature of extensive competition between them.

Looking ahead, we see a new technology for the next generation of high-speed transport, the Maglev. A business plan to introduce the Maglev system between Tokyo and Nagoya by 2025 has recently been released. We thus need to anticipate a new high-speed inter-city transport system with three different modes of travel.

This paper highlights the historical landmarks of how high-speed railway and air transport developed in Japan, and takes a look beyond the horizon of future inter-city transport. Various transport statistics are compiled and analysed in an attempt to underpin the characteristics of these transport modes. We also set up a dynamic spatial nested logit model to assess the nation-wide impact of the Maglev Super-Express.

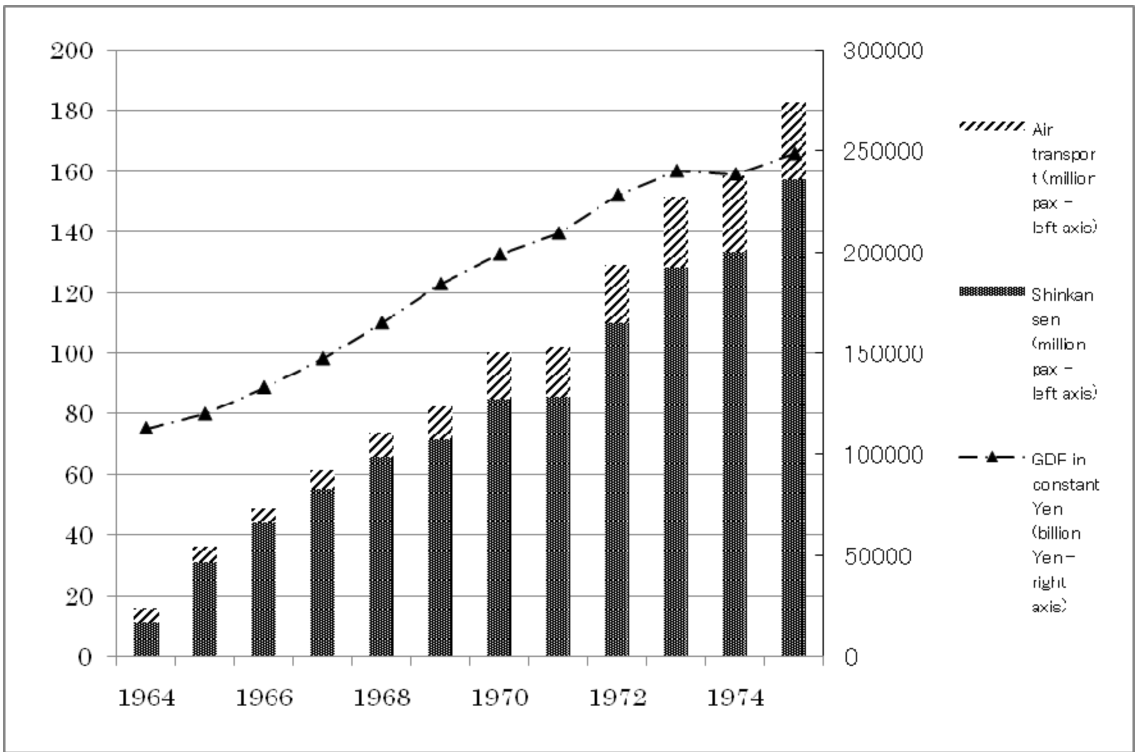
2. THE EVOLUTION OF HIGH-SPEED INTER-CITY TRANSPORT IN JAPAN

2.1. 1960-70

In October 1964, in the era when the maximum speed on the railway system was 120km/h, Shinkansen with a maximum speed of 210 km/h was considered as the super-express "dream come true". The previous seven-hour trip between Tokyo and Osaka, 550 km in length, was cut to four hours and ten minutes by the initial bullet train. At first, ten "Hikari" super-express trains that only stopped at Nagoya and Kyoto between Tokyo and Osaka, and ten "Kodama" express trains that stopped at other stations were operated. The first fleet consisted of twelve cars with a total of 987 seats. The capacity of passenger railway transport between Tokyo and Nagoya increased by 42% even though the rapid train service on the existing network was reduced by more than 30%. Within one year

Shinkansen was speeded up to shorten the trip between Tokyo and Osaka to three hours and ten minutes. Frequency was increased to 55 round-trips per day. The fare between Tokyo and Osaka by Hikari was 2 480 yen. In six months, Shinkansen's ridership reached 11 million. In particular, speed and price significantly attracted business trip-makers. Figure 1 shows that by 1970 the annual Shinkansen passenger ridership reached 85 million.

Figure 1. **Demand for air transport and Tokaido Shinkansen in passenger-kilometres (1964-1975)**



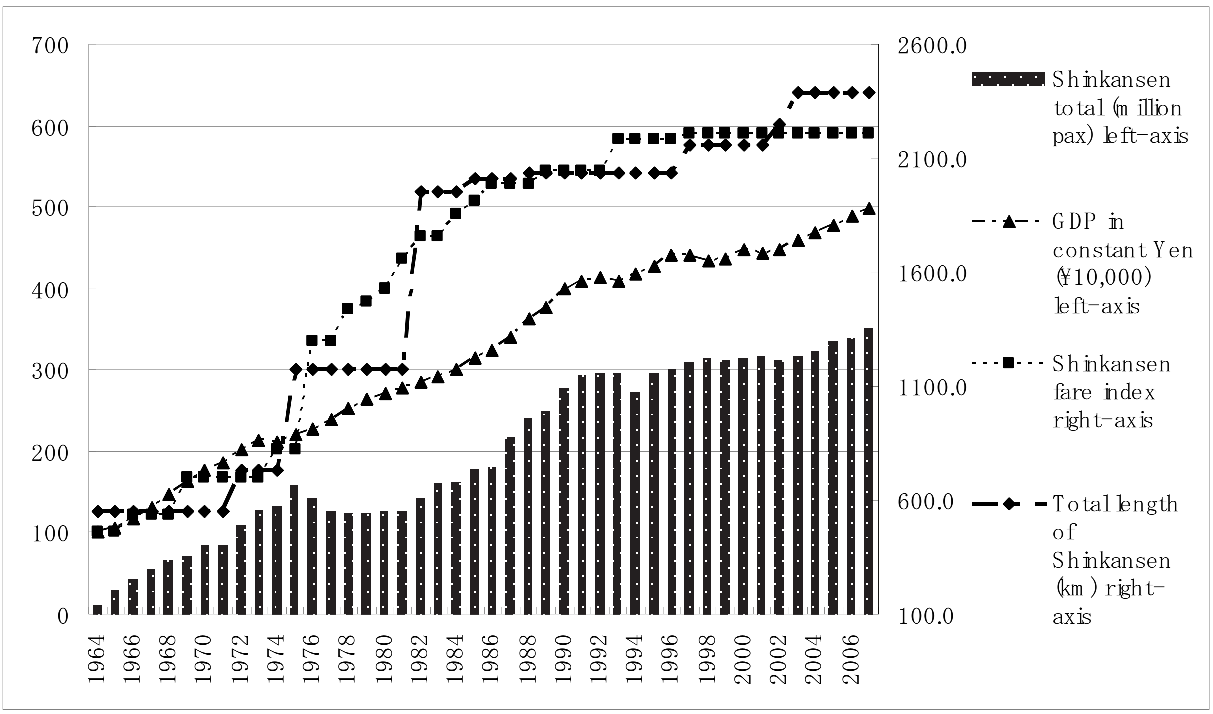
At the initial stage of air transport development, the national flag carrier, Japan Air Lines (JAL), operated on international routes and domestic trunk routes. Routes between Tokyo, Osaka, Sapporo, Fukuoka and Okinawa were designated as domestic trunk routes. Other airlines were assigned to operate on domestic local routes. An increase in demand and severe airline competition called for a new framework to secure fair competition and the orderly development of the market. A 1970 policy recommendation by the Transport Policy Council under the Ministry of Transport[1] and the Ministerial Order of 1972 outlined the subsequent regime for air transport in Japan. Under this so-called 45/47 regime[2], JAL was to serve on international and domestic trunk routes, All Nippon Airways (ANA) on domestic trunk and local routes and Toa Domestic Airlines (TDA)[3] on domestic local routes. This regime continued to be the framework for Japanese air carriers until the mid 1980s.

When Shinkansen started its operation in 1964, air transport was at the initial stage of introducing turbo-jet aircrafts. The first turbo-jet to fly in the domestic market was the Conveyer 880 on the Tokyo-Sapporo route in 1961. By 1964, Boeing 727 and DC8 joined the fleet of Japanese air carriers. The Tokyo-Osaka route, however, was still operated by turbo-prop aircrafts when Shinkansen started its operation. In those days, the average speed of domestic air transport was 333 km/h and it took an hour and forty-five minutes to fly from Tokyo to Osaka. During the first six months of Shinkansen's operation, 3.6 million passengers, equivalent to 14% of the Tokyo and Osaka air transport market, shifted to rail. Despite the dramatic success of Shinkansen, air transport marked rapid growth in the subsequent years. By 1970, the annual number of air transport passengers was above 15 million.

2.2. 1970-90

In 1972, Shinkansen was stretched to Okayama, 150 km west of Osaka, and then in 1975 to Hakata in North Kyushu, 644 km from Osaka. Now, Shinkansen was composed of 553 km of Tokaido Shinkansen and 644 km of Sanyo Shinkansen. Between 1965 and 1975, Shinkansen enjoyed 15% annual growth in passenger ridership and reached 157 million by 1975.

Figure 2. **Historical data regarding Shinkansen (1964-2007)**

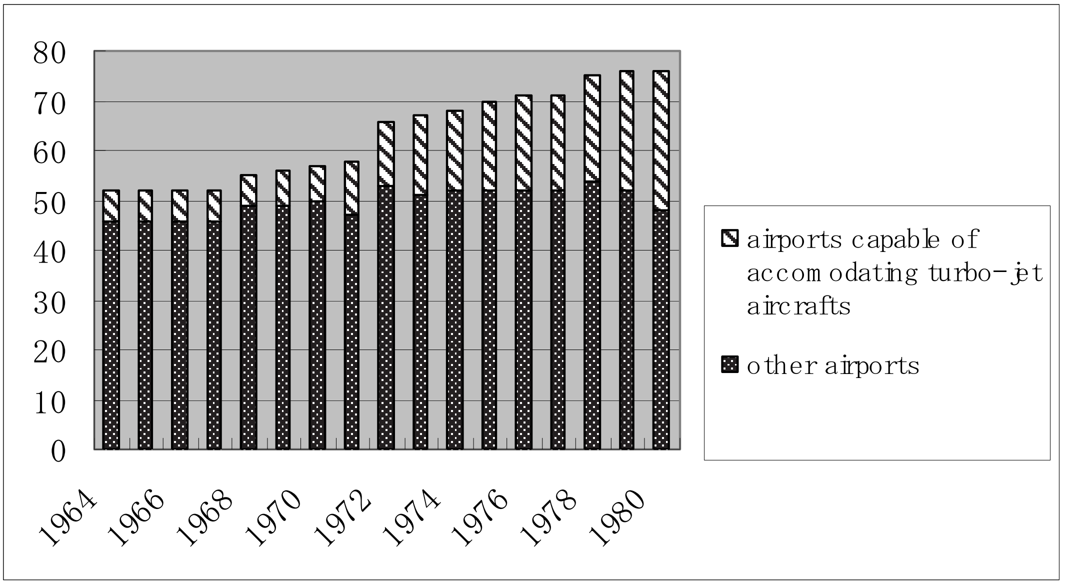


In the following years, however, Shinkansen demand started to decline. Apart from the economic downturn due to the exchange rate reform of 1971 and the oil crisis in 1973, Japan National Railways (JNR) was suffering from a huge financial deficit, accumulating year by year. Investment, maintenance and operation costs were basically self-managed by JNR. The rapid motorisation in urban and regional transport led JNR into severe financial distress. In particular, the expansion of the rail network in rural areas amplified the problem. JNR's accumulated losses skyrocketed from 83 billion yen in 1965 to 678 billion yen in 1975 and was still growing fast. The government and JNR took steps to alleviate their financial difficulties by increasing fares. A one-way Shinkansen ticket from Tokyo to Osaka, initially set at 2 480 yen, was hiked to 5 050 yen by 1974 and reached

10 800 yen by 1981; a four-fold increase in 17 years. JNR's price hike had over-ridden the CPI and the Tokyo-Osaka air fare, which rose by 2.7 times and 2.3 times, respectively, during the same period. Railway fares continued to be increased until JNR was privatised in 1987. By then, a Shinkansen ticket from Tokyo to Osaka cost 13 100 yen. The historical data depicted in Figure 2 illustrates the effect of the price hikes.

Demand for air transport had also stagnated during the late 1970s but not as severely as for Shinkansen. Turbo-jet aircraft, with faster speeds and greater capacity than turbo-prop aircraft, were introduced rapidly. As shown in Figure 3, the number of airports accommodating turbo-jet aircraft was increased from six in 1965 to 28 in 1980.

Figure 3. **Number of airports in runway categories (1964-1980)**



Class One international airports in Tokyo and Osaka were built and funded 100% by the government[4]. The central government was also task ed to own and operate Class Two airports in major cities, such as Sapporo and Fukuoka. Two-thirds of the funding was assured by central government and the rest covered by local government. Class Three airports in local cities were built and managed by local governments with half of the investment subsidized by central government. In 1967, the first of the Five-Year Airport Construction Plans was adopted. In 1970, central government established a Special Account for Airport Development, to invest and maintain the Class One and Two airports and subsidize the Class Three airports. The financial sources for the Special Account were twofold. One source was direct income from landing fees and 11/13 of the jet fuel tax levied on domestic air transport operation, sourced through the General Account of the Japanese Government. This accounts for 70%-80% of the total revenue. The rest is composed of generic funds from the General Account and provisions from the local government for Class Two airports. In the 1980s, government loans were injected into the Special Account for Airport Development to finance large investments in Haneda Airport. In 1966, the New Tokyo International Airport Agency (Narita) was established by the government. After twelve years of difficulty, Narita Airport was opened in 1978. International flights were basically shifted from Haneda to Narita, giving room to facilitate untapped demand in the domestic air transport market.

In the 1980s, Japan steadily recovered from the economic shocks. Rapid growth was experienced in both the international and domestic air transport markets. In 1985, the Transport Policy Council reviewed the 45/47 framework and recommended that the government should to turn to a pro-competitive policy. The operation of multiple numbers of airlines on routes was liberalized on high-density routes. The threshold demand level, allowing two airlines (double tracking) and three airlines (triple trucking) to operate, was set out by the Ministry of Transport. Thresholds of double/triple tracking were cut down in 1992 and in 1996 for the further promotion of competition. In 1997, the threshold itself was abolished so that any number of airlines could enter into any route regardless of the volume of that route. As a consequence, the ratio of available seats on routes with multiple numbers of airlines against total available seats in the domestic air transport market rose from 53% in 1985 to 80% in 1999. The new aviation policy, set out in 1985, also allowed airlines other than JAL to operate on international routes and JAL was privatised.

Domestic airfares were regulated to control airfares based on cost. When the airlines applied for an increase in airfares due to inflation or an upspring in the price of fuel, etc., the overall cost of airline operation was reviewed by the government. An airfare increase was only allowed up to the level justified by aggregate cost under efficient operation. Such an "aggregate cost formula" was common for public utilities.

2.3. 1990-Present

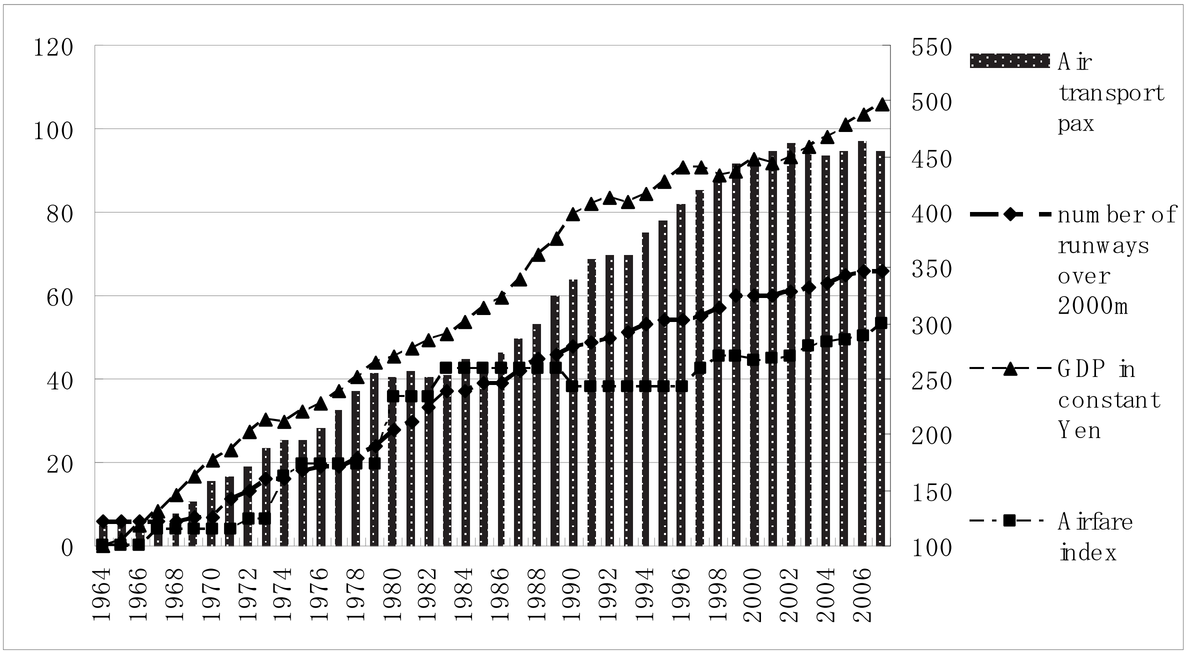
2.3.1 Liberalization in the air transport market

Due to the burst of the "economic bubble", the Japanese economy plunged into recession and prices became deflationary in the early 1990s. The opening of Kansai International Airport in 1994 would have been welcomed more if it were not for the great depression. The private sector was facing difficulties, with deteriorating demand and prices. Public utilities including transport services, however, tried to pass excessive costs to the consumer by raising prices. As from 1994, strong criticism over price hikes for public utilities pushed the regulatory reform of public utilities into a policy agenda. Amidst countervailing forces, airfare regulation was deregulated to introduce a "zone airfare scheme". This allowed airlines to obtain automatic approval within a specific zone. The new zone airfare system provided airlines with flexibility when setting air fares. Seasonal differences and flight-by-flight pricing were now possible. In 1996, the airlines' applications were approved under the new regulation. Under the new price regulation regime, incumbent airlines increased the normal fares for trunk routes while introducing various discount fares, such as advance booking discounts and frequent flyer programmes (FFPs). Despite the introduction of various discount fares, normal airfare hikes on trunk routes such as Tokyo-Fukuoka and Tokyo-Sapporo were confronted with strong criticism in the Fukuoka and Sapporo regions.

This opened a window of opportunity for entrepreneurs to set up new airlines. Airport capacity expansion of the highly congested Haneda Airport was under construction. In March 1997, a new runway was opened and 40 landing slots per day were added. These slots were allocated to airlines in two stages: July 1997 and April 1998. At that time, there were six projects launched to raise new airlines and the first two to be in the market were Skymark Airlines in September 1998 and Hokkaido International Airlines (AIR DO) in December 1998. They entered into Tokyo-Fukuoka and Tokyo-Sapporo routes respectively. Apart from subsidiaries of the major three air carriers, it was indeed the first new air carrier entry in 35 years. At the launch of their services, the two airlines set out much lower airfares compared to incumbent carriers. Skymark offered half the normal fare and AIR DO was 36% below the incumbents. This "everyday low fare" strategy became popular and their load factor rose as high as 80%. On the other hand, incumbent carriers suffered a sudden drop in passengers.

These routes were lucrative trunk routes with many business travellers. The incumbent carriers started to offer discount fares on flights just before and after the flights of new entrants. They also upgraded their frequent flier programmes. These counter measures were quite effective and by March 1999 the incumbent carriers regained their demand at the same level as that of the previous year. Enhanced competition facilitated annual passenger increase in Tokyo-Fukuoka route and Tokyo-Sapporo route, by 16.3% and 9.4%, respectively. From then on, a pro-competitive slot allocation policy at congested airports such as Haneda Airport became an important agenda for the Ministry of Transport. The new policy was introduced to review slot allocation in congested airports every five years. Figure 4 illustrates the historical trend in air transport. It could be observed that despite economic stagnation in the mid-1990s, air transport experienced moderate growth due to market stimulation from deregulation.

Figure 4. **Historical data regarding air transport (1964-2007)**



In Japan, deregulation in the transport sector has been implemented in steps. In December 1996, with a view to accelerate deregulation in every transport sector and to promote administrative reform, the Ministry of Transport decided to abolish supply/demand testing in the entire transport sector by the end of the century. Based on the report from the Transport Policy Council of April 1998, the air transport market was totally liberalized while measures for maintaining essential air services to remote islands and the rule for slot allocation in congested airports were reinforced. Having set out necessary measures for liberalization, the Civil Aeronautics Law was amended and put into effect in February 2000, so that supply/demand regulation policy was abolished and a licence for each route was no longer needed. The airfare regulation was also deregulated from approval regulation to prior notification. With regard to the congested airports, slot allocation was adopted, subject to review every five years based on pre-set allocation criteria.

According to Yamaguchi (2005), from 1980-98, the accumulated increase in consumer surplus from deregulation and public investment related to air transport amounted to 1.2 trillion and 3.5 trillion yen, respectively.

2.3.2 JNR reform and Shinkansen

The year that Shinkansen started its operations was the year that the JNR's severe financial problems became apparent. In 1964, JNR reported its first operating loss, which then grew year by year. By 1966, the capital reserve dwindled and net losses started to accumulate. In 1971, JNR reported an operating loss before depreciation. Fares were raised almost every year. Total government subsidies reached 6.6 trillion yen. Despite these measures, long-term debt reached 37.1 trillion yen, of which 15.5 trillion yen was JNR's accumulated loss. In 1987, the government put an end to JNR's financial crisis through privatisation. The JNR's reform package of 1987 was composed of the following:

a) Privatisation of JNR into six regional passenger railway transport corporations and one freight transport corporation;
b) Shinkansen would be held by a special-purpose government agency and leased to JR companies;
c) 11.6 trillion yen of the total 37.1 trillion yen long-term debt would be borne by major JR companies and the rest, 25.5 trillion yen, by a special-purpose government agency.

In 1993, JR East was floated on the stock market, followed by JR West and JR Central in 1996 and 1997, respectively. In 1991, Shinkansen assets, spun-off in the 1987 JNR reform package, were bought back by the three JR companies. The final solution to the 25.5 trillion yen long-term debt, borne by a special-purpose government agency, was achieved in 1998.

A law stipulating a nationwide plan for Shinkansen development was enforced in 1970. Under the plan, agreed in 1973, an extension of the network – northwards to Sapporo in Hokkaido and southwards to Kagoshima in Kyushu – and the development of the Hokuriku Shinkansen, connecting Tokyo and Osaka via Nagano and Toyama, were included in the development plan phase. These new routes were christened *Seibi-Shinkansen*.

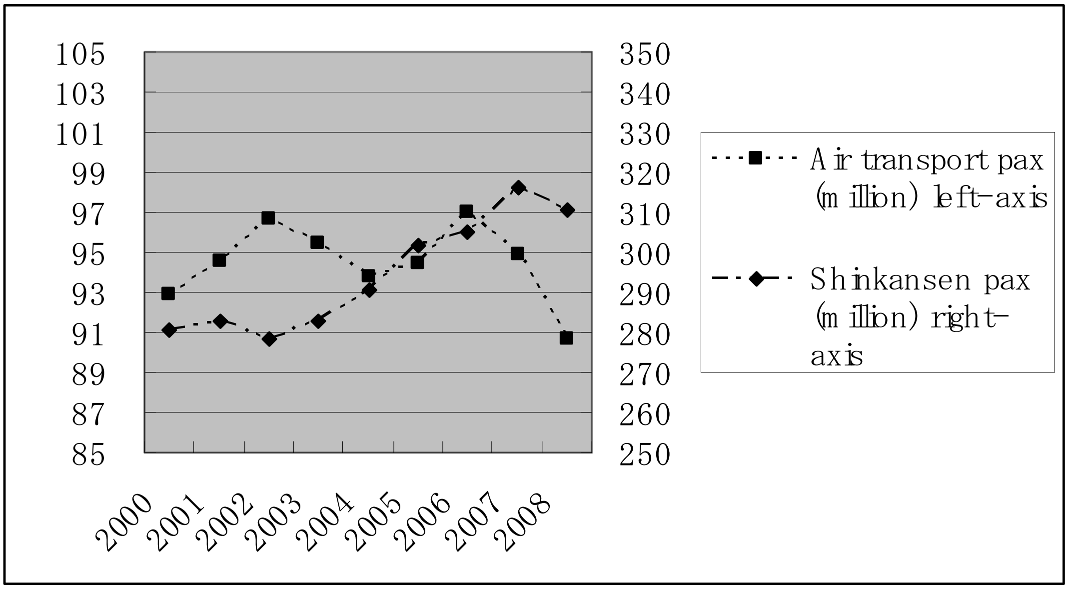
Over-investment was one of the major causes of financial turmoil for JNR. Thus, an important feature of the new Shinkansen funding scheme was to avoid a new financial crisis. A funding scheme, established in 1989 for the extension to Nagano – the first of the routes to be constructed as *Seibi-Shinkansen* – comprised 50% JR investment, 35% by central government and 15% by local government. The funding scheme was revised in 1996 so that JR would only bear investment costs up to a level where they would still benefit. The rest of the investment would be covered by the government: two-thirds by central government and one-third by local government.

2.4. Towards the future

2.4.1 Shinkansen and air transport

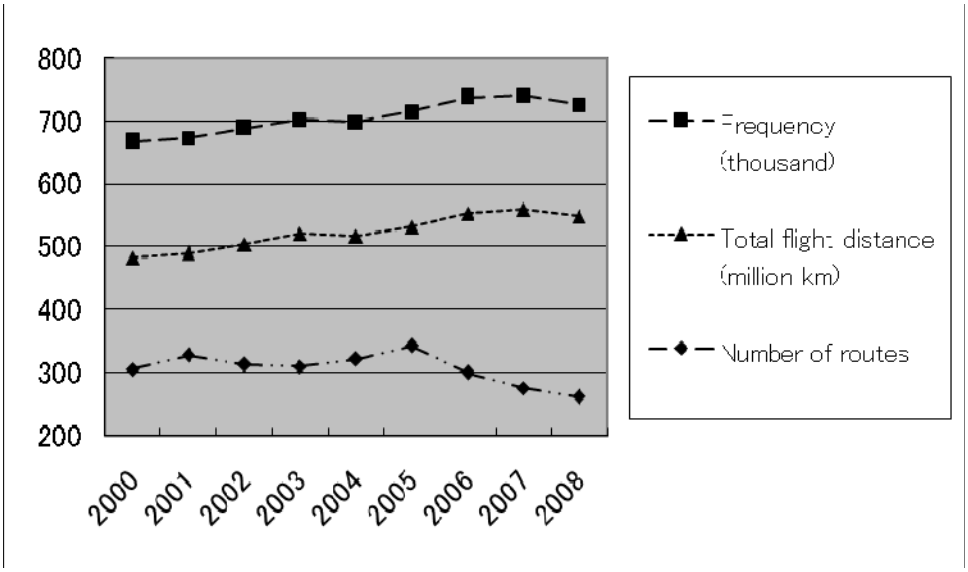
With the turn of the century, Shinkansen constantly increased its demand and, in recent years, a complementary relationship with air transport has continually been manifested. Figure 5 shows the recent annual number of Shinkansen passengers in comparison with those of air transport.

Figure 5. **Recent trend of passengers on air transport and Shinkansen (2000-2008)**



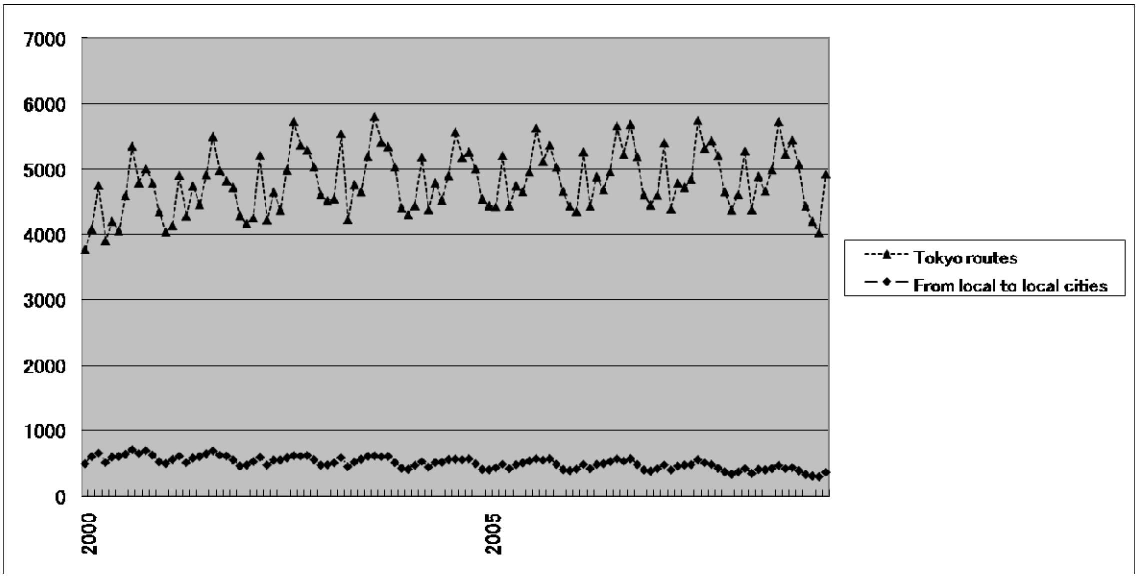
The extension of the existing Shinkansen under operation currently represents a total of 2 387 km. 1 173 km of the *Seibi-Shinkansen* network are unfinished, and due to constraints on government funds, it is estimated that it will take about ten years to be completed. Apart from the *Seibi-Shinkansen*, the Maglev Super-Express is planned to be built as part of the grand design of the national Shinkansen network, as stipulated under the National Shinkansen Law of 1970. The major difference between *Seibi-Shinkansen* and the Maglev Super-Express is that the latter is declared to be self-financed by JR Central.

Figure 6. **Recent trend of air transport (2000-2008)**



Since the turn of the century, except for 2005 when Chubu Centrair International Airport was opened, the total number of routes for domestic air transport has seen a gradual decline. On the other hand, as depicted in Figure 6, total frequency and total flight distances have increased. Routes to and from Tokyo (Haneda) are increasing in capacity and demand, while other routes, local-to-local routes in particular, are losing both. Route concentration has led the overall average frequency per route to increase by about 30% between 2000 and 2008. Figure 7 shows the trend in the number of monthly passengers on routes to and from Tokyo and local-to-local cities. While demand for Tokyo routes increased by 10%, local routes decreased by 35%.

Figure 7. **Monthly number of passengers in thousands on routes to and from Tokyo and between local cities (Jan. 2000- Mar. 2009)**



As for total domestic air transport demand, with the rise of fuel costs, the average fare (yield) per passenger-kilometre has increased from 15.0 yen/per km in 2002 to 17.6 yen/per km in 2008. As a result, the total number of passengers has declined from 96.7 million in 2002 to 90.7 million in 2008. The merger of JAL and JAS in 2002 also had an impact on the market in general. Figure 8 illustrates the recent trend.

Figure 8. **Recent trend of passengers and average price of air transport (2000-2008)**

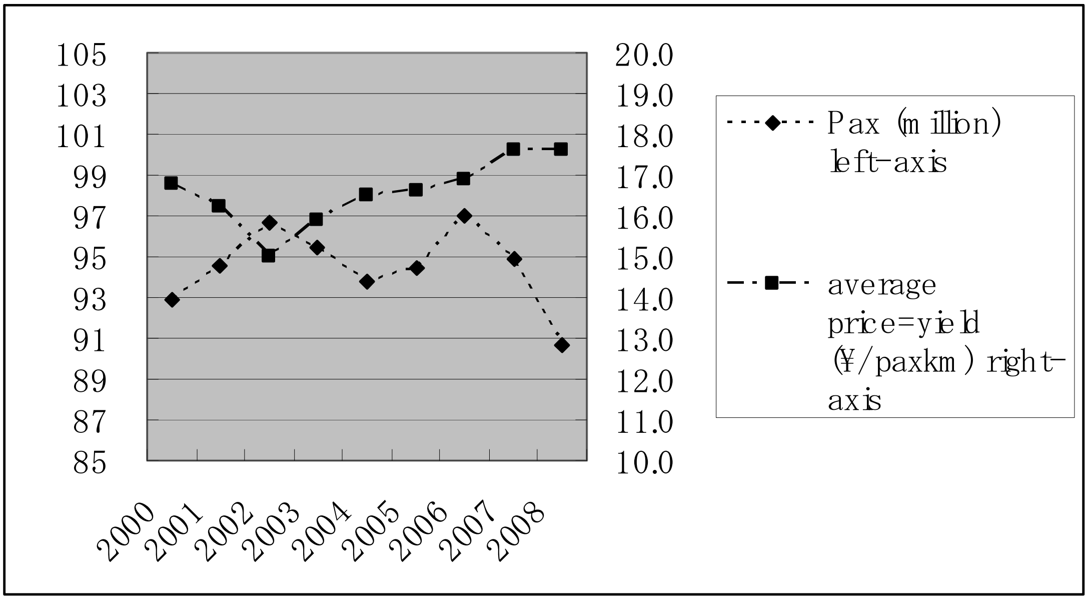


Figure 9 shows the profound effect of the world-wide economic downturn since September 2008 on air transport and Shinkansen. Both transport modes have experienced unprecedented decreases in demand in recent months. Speculators view February 2009 as the lowest point. There are hopes that the transport market, mirroring the general economic activity, will rebound in the foreseeable future.

Figure 9. **Percentage change of monthly passengers on air transport and Shinkansen (March 2007- March 2008)**

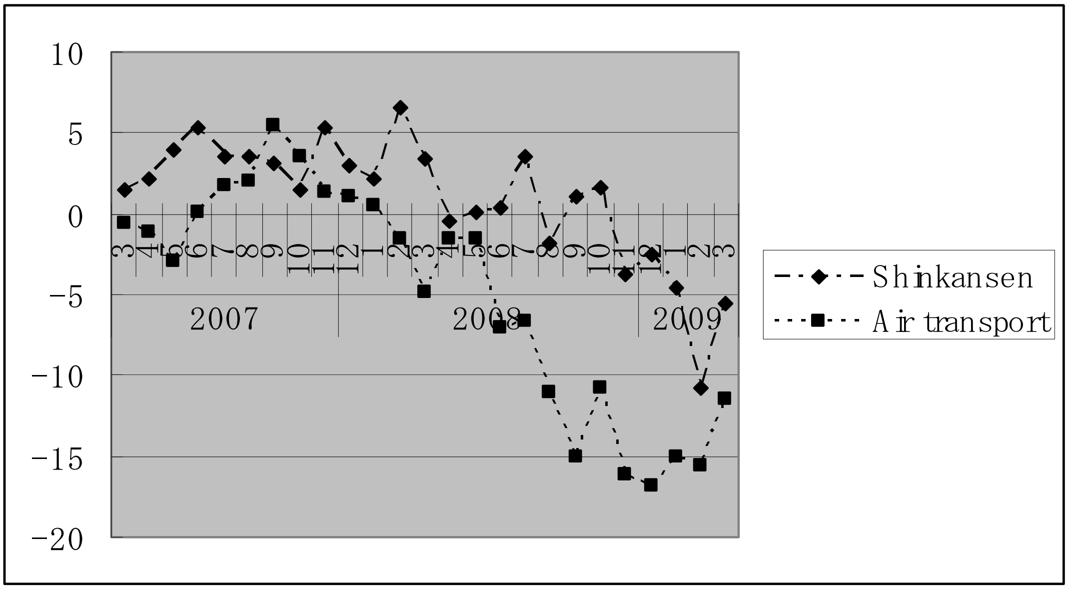
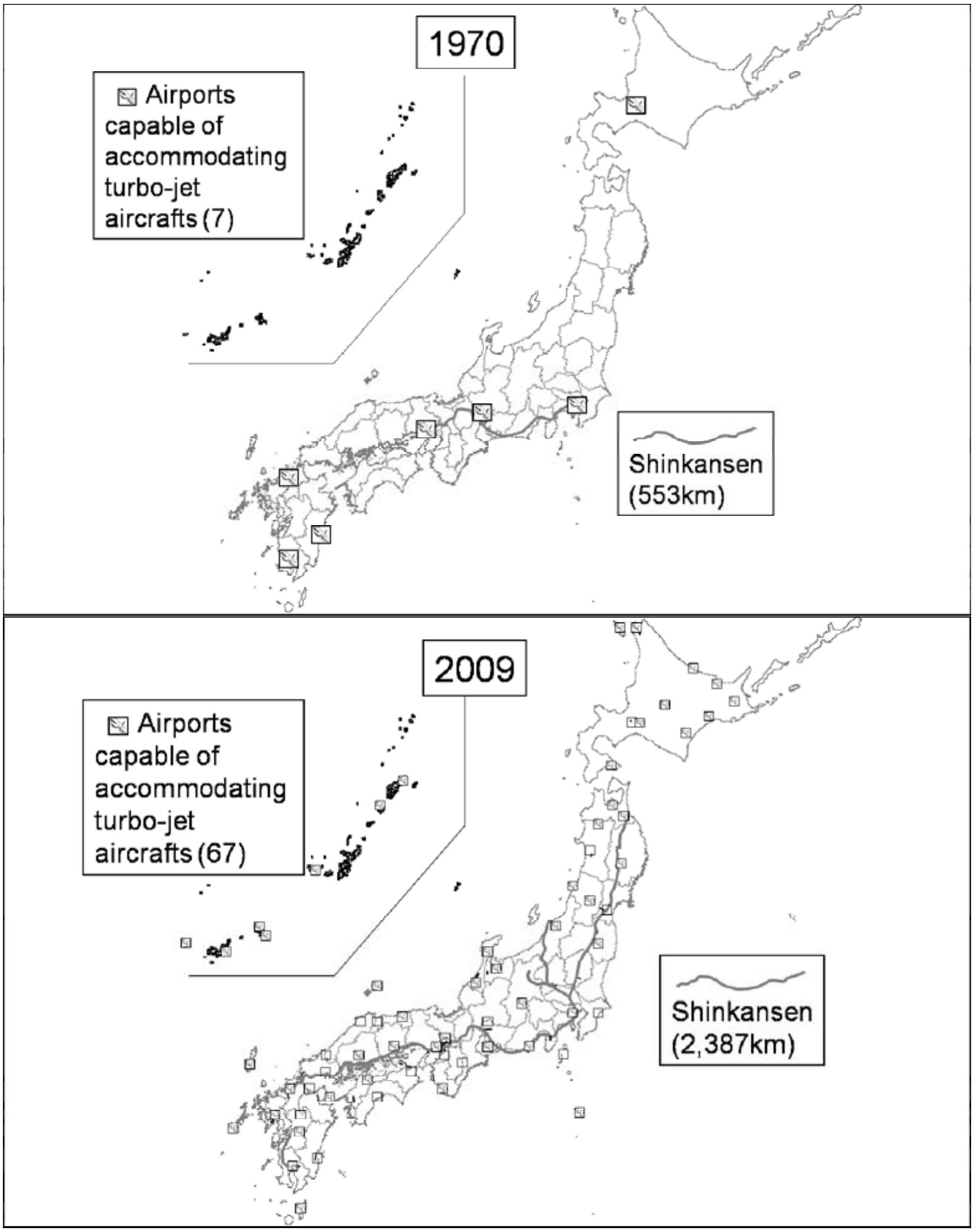


Figure 10 gives snap-shots of the Shinkansen network and airports in 1970 and 2009. It should be noted that regional airport development has basically come to an end. Now there is a need to facilitate the increase of capacity in the Tokyo metropolitan area. In 2010, landing slots in Tokyo Haneda Airport and Narita International Airport are to be increased substantially. In particular, the opening of the fourth runway at Haneda Airport is expected to have a profound impact on domestic and near-by East Asian inter-city air transport. In 2009, there were 806 domestic flights and 24 international charter flights operating daily at Haneda Airport. Domestic flights should be increased to 826 in October 2010 and then to 880 within six months thereafter.

Figure 10. **Shinkansen network and airports in 1970 and 2008**



Back in 1978, when Narita International Airport was opened, international scheduled flights were basically shifted away from Haneda Airport. With the 2010 expansion, Haneda Airport will accommodate 40 international scheduled flights daily to major near-by East Asian cities during the day and another 40 international flights between late evening and early morning. Furthermore, another 72 flights should eventually be added, the allocation of which is still to be determined.

2.4. The Maglev

The technology of the super-conductivity magnetic levitated super express, the so-called "Maglev", goes back to 1962. Ten years after the start of the research project in JNR, the first test operation was undertaken on a 220-metre strip test guideway at a research centre in Kunitachi, Tokyo. In 1974, construction of a 7-kilometre testing lane was initiated in Miyazaki, where test runs were conducted until the test bed was switched to Yamanashi in 1996. In the current 42.8 km stretch of test-course in Yamanashi, a maximum speed of 581 km/h was recorded in 2003 and in that year the government technology committee announced that the Maglev Super Express was now technologically feasible. By 2006, accumulated test runs had exceeded 500 000 km and in 2007, the test course was designated to be part of the commercial path of Chuo Shinkansen. That year, JR Central announced that they planned to open the Tokyo-Nagoya Maglev Super Express by 2025, and would be the sole investor in the 500 trillion yen project.

Chuo Shinkansen is listed as one of the routes to be developed under the National Shinkansen Development Law. The Maglev Super Express planned by JR Central is an integral part of the Chuo Shinkansen. Currently, there is debate over which specific route the Chuo Shinkansen should take. Local governments are requesting diversion of the route to local cities which would inevitably increase the construction cost of the overall Maglev infrastructure.

Table 1. **Comparison of Shinkansen, Maglev (plan) and air transport**

	Tokyo-Nagoya (366km*)			**Tokyo-Osaka (553km*)**		
	Time	**Fare**	**CO2/pax**	**Time**	**Fare**	**CO2/pax**
Shinkansen (Nozomi)	103min	10 780yen	5.2kg	156min	14 050 yen	7.9kg
Maglev (plan)	40min	(11 780 yen)	15.7kg	60min	(15 000 yen)	23..8kg
Air	-	-	-	68min	13 600 yen	68.8kg

*Distance in railway mileage.

Table 2. **CO_2 intensity**

Mode	**CO_2 -g/paxkm**
Shinkansen	14.2
Maglev	43.0
Air	124.5

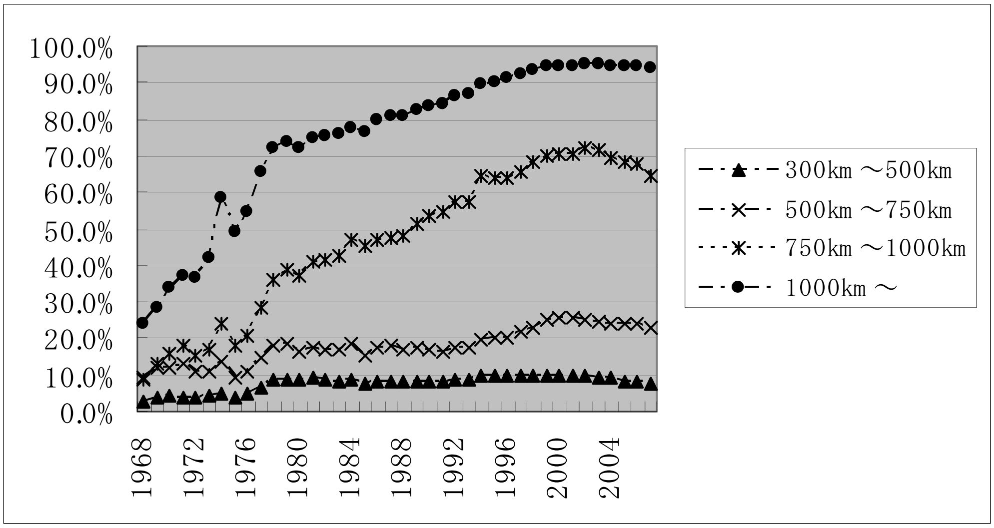
3. MARKET CHARACTERISTICS OF A HIGH-SPEED, INTER-CITY TRANSPORT SYSTEM

3.1. Average travel distance of Shinkansen and air transport

Originally, Shinkansen was utilised for long-distance travel, the majority of journeys exceeding 300 km. By 2007, however, more than half of Shinkansen ridership was for trips of less than 300 km. The average distance declined from 319 km in 1968 to 234 km in 2007. The breakdown of Shinkansen average travel distances into segments is as follows: Tokaido=308 km, Sanyo=251 km, Tohoku=168 km, Jouetsu=126 km, Hokuriku=82 km, Kyushu=103 km. Only Tokaido Shinkansen is maintaining an average ridership of more than 300 km.

On the other hand, the average trip length for domestic air transport has increased over time: 605 km in 1968 and 881 km in 2007. Average distances for Shinkansen and air transport have been diverging over the years. As a result, the modal share of air transport in long-distance travel has been increasing, as depicted in Figure 11.

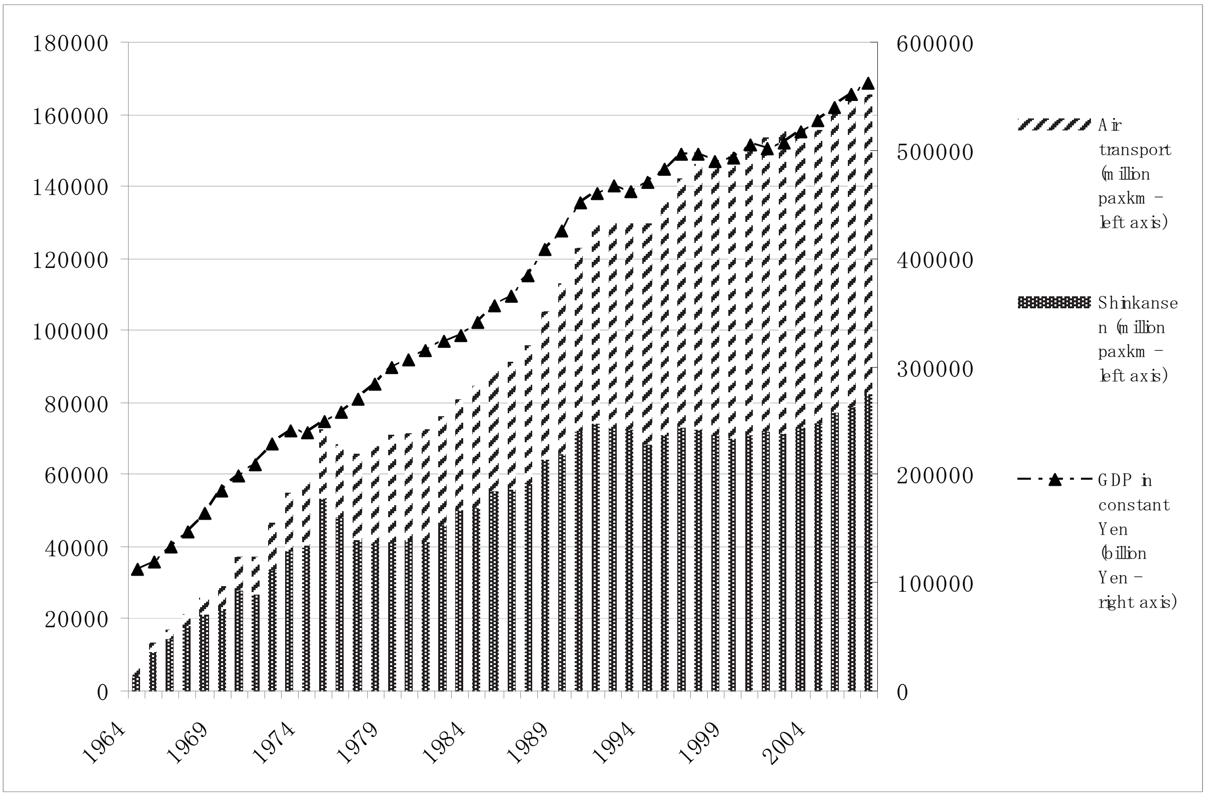
Figure 11. **Trend in share of air transport in distance groups**



3.2. Modal split between Shinkansen and air transport

From Figure 12, the aggregate demand growth of Shinkansen and air transport has basically paralleled that of GDP. When Shinkansen ridership growth stagnated between 1975 and 1985, air transport seems to have filled the gap. In order to clarify this modal choice relationship, the following logit model was estimated.

Figure 12. **Trend in GDP and passenger kilometres of Shinkansen and air transport**



3.2.1 Logit model

Here we conduct a logit model analysis using pooled historical data. Let U_k be the utility of choosing transport mode k composed of deterministic portion V_k and random variable δ so that,

$$U_k = V_k + \delta .$$

There are two transport modes, railway (R) and air transport (A). Let V_k be a function of price and defined as follows:

$$V_k = \alpha + \beta p_k$$

Where:

p_k represents fare of mode k, and

α, β are parameters.

The probability of choosing air transport or railway would be:

$$P_A = \frac{\exp(V_A)}{\exp(V_R) + \exp(V_A)} \text{ and } P_R = \frac{\exp(V_R)}{\exp(V_R) + \exp(V_A)}.$$

Let X be total demand of air transport and railway. Then,

$X_A = s_A X = P_A X$ and $X_R = s_R X = P_R X$. Thus,

$X_A / X_R = P_A X / P_R X = P_A / P_R = \exp(V_A) / \exp(V_R)$.

Taking the natural log of both sides, the formula to be estimated is as follows:

$$\ln[X_A / X_R] = \ln[P_A / P_R] = \alpha + \beta(p_A - p_R) + \varepsilon$$

Where ε is the error term.

3.2. *Description of data*

Ridership statistics are available for both Shinkansen and air transport. While route segment data is available for air transport, railway on-board segment data, including that of Shinkansen, however, is not available. It is not possible to discern how many passengers get onboard Shinkansen at Tokyo and get off at Osaka from railway statistics.

In order to identify inter-prefectural transport, a Regional Passenger Flow Survey has been conducted annually since 1960. Through this survey it is possible to know how many people travelled between and within the 47 prefectures. A breakdown into different modes of travel is provided. Therefore, it is possible to know how many people travelled between Tokyo Prefecture and Osaka Prefecture. When a multi-modal trip is made, each rider on an individual mode is counted as one. Also, the purpose of travel is unknown. However, even given these limitations, the survey does give valuable inter-prefectural data.

In order to complement the unknown factors, a Trunk Route Passenger Flow Survey has been conducted every five years since 1990. The latest survey was conducted in 2005. This detailed survey is conducted for a single day in autumn and compiled into 207 zones. The level of transport service between zones is compiled from publicly available timetables.

There are two datasets for X. Data-set A is composed of the number of annual passenger-kilometres performed by Shinkansen and air transport (1965-2007). Data-set B is composed of the total number of trips made over 300 km by railway and air transport (1968-2007). As for transport cost p, Shinkansen and the airfare between Tokyo and Osaka are chosen as representative price data (1964-2007). Prices are inflation-adjusted by the Consumer Price Index. These data are pooled and regressed by the ordinary least-square method.

3.2.3 *Result of the estimate*

The estimates of β for the two datasets are -1.2 and -1.7, respectively, and both statistically significant (Table 4). They are consistent with past studies.

Table 3. **Modal split parameter**

Parameters	**Data set A**		**Data set B**	
	Parameter	**t-ratio**	**Parameter**	**t-ratio**
Constant(α)	0.070	1.194	0.399	4.682*
Transport cost（ β ）	-1.242	-11.804*	-1.711	-9.535*
R^2	0.699		0.705	
Sample size	43		40	

*Significant at 1% level.

Average own-price elasticity $\left|\beta p_k (1 - s_k)\right|$ and average cross-price elasticity $\left|\beta p_k s_k\right|$, calculated from estimated parameter and data sets A and B, are listed in Table 4. These figures are consistent with past studies.

Table 4. **Average price elasticity**

	Data set A	**Data set B**
Own price elasticity (average)	0.70	0.89
Cross price elasticity (average)	0.94	1.51

The transport demand share between air transport and Shinkansen, or travel over 300 km by air transport and railway, is significantly correlated with the relative price difference. In this model, however, spatial conditions and speed factors are ignored. In order to analyse the air-rail relationship in a more comprehensive manner, we need to develop a spatial model that breaks region into zones, as well as to take different trip purposes into account. Looking into the future, there is also a need to consider changes in population, economic growth and new technology for inter-city transport. In the following section, we develop a nationwide inter-city transport demand model to assess the impact of the Maglev Super-Express.

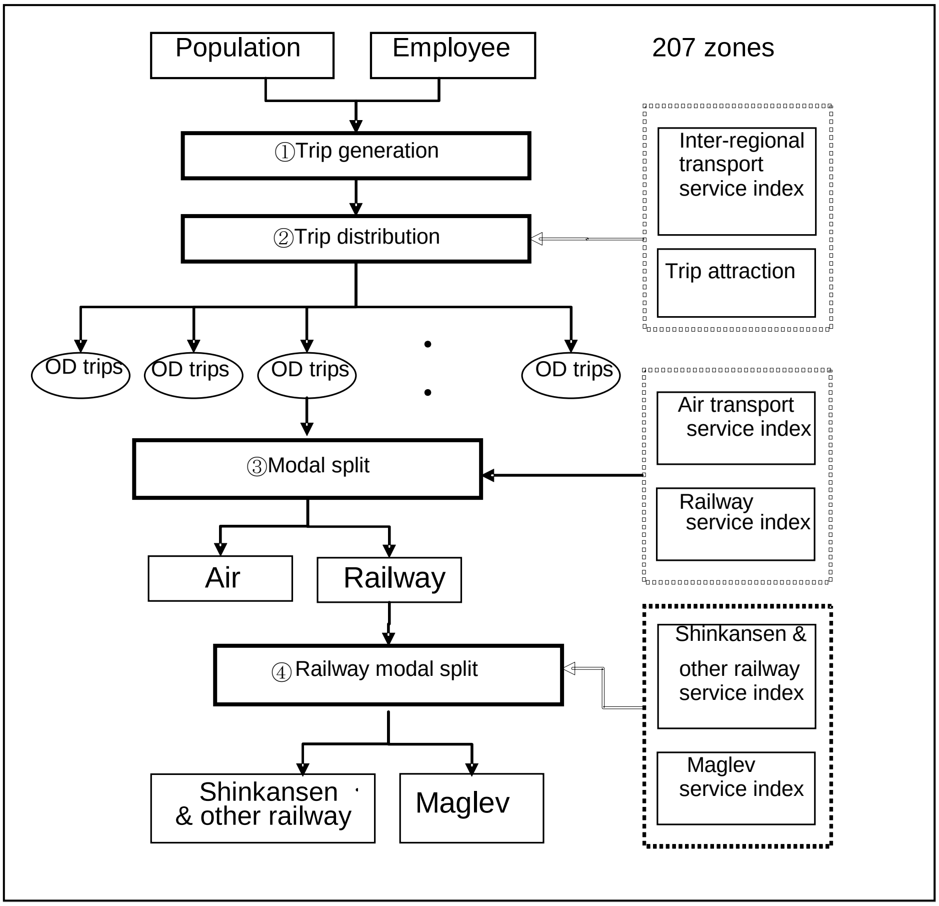
4. SIMULATION ANALYSIS OF A FUTURE HIGH-SPEED INTER-CITY TRANSPORT SYSTEM WITH MAGLEV

4.1. Model structure

The model is structured in four stages, as illustrated in Figure 13.

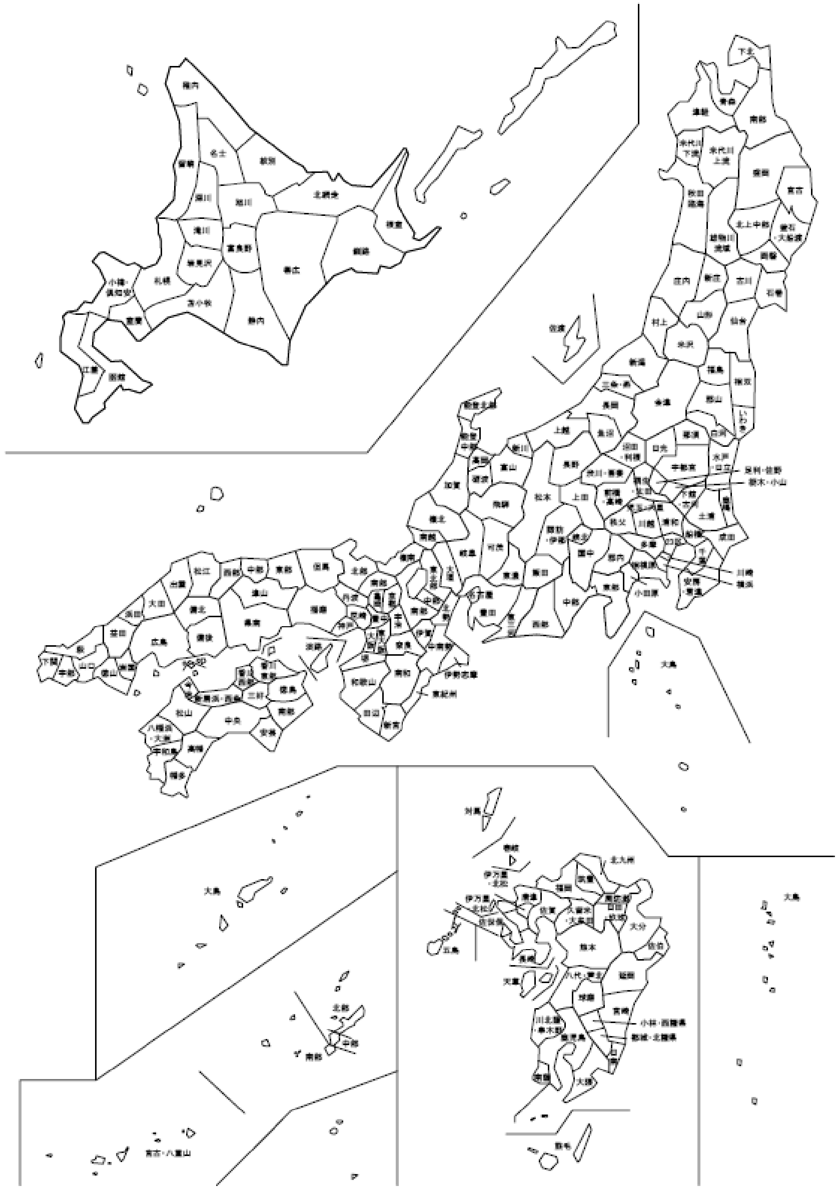
1. National trip generation model;
2. Zone-to-zone trip distribution model;
3. Air *vs.* rail modal split model;
4. Shinkansen and other railways *vs.* Maglev choice model.

Figure 13. **Model structure**



The spatial inter-city demand model is developed by breaking Japan into 207 zones, as depicted in Figure 14. The model is separated into three different trip purposes: business, tourism and private.

Figure 14: **Japan in 207 Zones**



4.2. Trip generation model

4.2.1 Model structure

Trip generation is modelled as a function of population and trips per capita. For business travel, the number of employees is used for population.

$$T_{im} = POP_{im} GA_{im} \qquad (1)$$

T_{im}: trip generation in zone i with trip purpose m
POP_i: population of zone i
GA_{im}: per capita number of trips from zone i trip purpose m

4.2.2 Trip generation model

Trip generation per capita is modelled as a function of level of service and price and income elasticities. The parameter is calibrated so that current trip generation per capita of that zone matches the model value.

$$GA_i = \beta_{0i} q_i^{\beta_1} (1 + n\eta) \qquad (2)$$

β_{0i}: parameter to be caliberated from current level of GA_i and accessibility index to other zones q_i
β_1: price elasticity
q_i: accessibility index derived form the trip distribution model
n: annual GDP growth rate
η: income elasticity

4.3. Trip distribution model

The objective of the trip distribution model is to allocate trips generated in a specific zone (zone i) to other destinations. We use a nested logit model to calculate the proportion of trips to destinations. From zone i, the probability of zone j being selected as a destination (P_{ij}) depends on the utility level of a trip between zone i and zone j (*Vij*) among the available destinations. The utility level of a trip between zones i and j depends on the service level of transport modes between the two zones (q_{ij}), and the attraction factor of the destination zone j (S_j). q_{ij} is derived from the log-sum of the transport mode selection model described below. The aggregation of trips destined to zone j is used as the attraction factor of zone *j.*

Parameter θ_1^D used in the log-sum factor is an estimated figure from the Annex.

$$q_i = \frac{1}{\theta_1^D} \ln\left[\sum_j \exp\left(V_{ij}\right)\right] \qquad (3)$$

$$P_{ij}^D = \frac{\exp\left(V_{ij}\right)}{\sum_j \exp\left(V_{ij}\right)} \qquad (4)$$

$$V_{ij} = \theta_1^D q_{ij} + \theta_2^D \ln S_j \qquad (5)$$

$$q_{ij} = \frac{1}{\theta_1^S} \ln\left[\exp\left(\theta_1^S q_{ij}^A + \theta_2^S\right) + \exp\left(\theta_1^S q_{ij}^R\right)\right] \qquad (6)$$

P_{ij}^D: probability of choosing zone j as destination

V_{ij}: utility of travelling between zones i and j

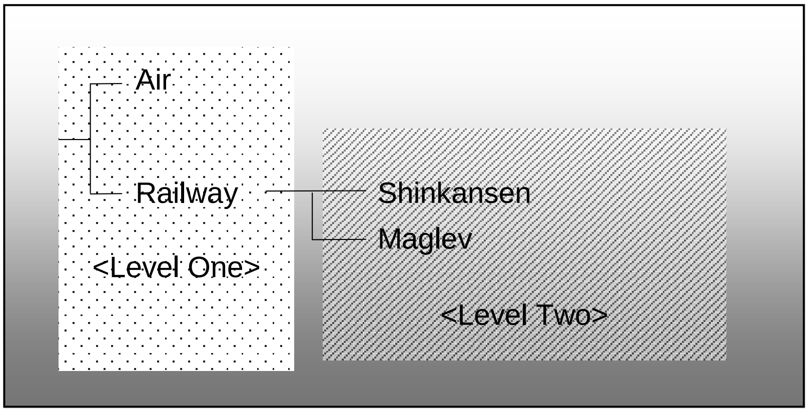
S_j: aggregate trip destination of zone j

q_{ij}: log sum value of travelling between zones i and j

4.4. Transport mode selection model

The transport mode selection model gives the modal split of the total trips between zones. We use a nested logit model. As depicted in Figure 15, the model is structured to provide two basic transport modes – “Air” and “Railway” – and a choice of “Shinkansen and other railway[5]” and “Maglev” for “Railway”.

Figure 15. **Transport mode selection model structure**



4.4.1 Level One

The probability of transport mode k being chosen for trips between zones ij is expressed in the form of an aggregate multi-nominal logit function. V_{ij} is the deterministic portion of the utility associated with mode k.

q_{ij}^{K} is the generalised price, composed of time factor and out-of-pocket costs. The value of time w is set exogeneously from past research (see Annex for details). In the case of the railway, the generalised price is the weighted average of Shinkansen and Maglev. θ_1, θ_2 are parameters to be estimated.

Following the utility function U_{ij}^{k} of travelling between zones i and j by transport mode k, composed of a deterministic portion $V_{ij}^{k} = \alpha + \beta p_{ij}^{k}$ and a random variable, assume that,

$$U_{ij}^{k} = \beta p_{ij}^{k} + \alpha + \varepsilon_{ij}^{k} \quad (7),$$

where $p_{ij}^{k} = M_{ij}^{k} + \theta T_{ij}^{k}$ is the generalised cost of travelling between zones i and j by transport mode k,

M_{ij}^{k} is the travel fare between zones i and j by transport mode k,

θT_{ij}^{k} is the product of θ, value of time, and T_{ij}^{k}, the time it takes to travel between zones i and j by transport mode k,

α is constant and β is a parameter, and

ε_{ij}^{k} is a random variable with Gumbel distribution.

Then, the probability of choosing mode travel by transport mode k between zones i and j could be expressed as follows:

$$P_{ij}^{k} = \frac{\exp\left(V_{ij}^{k}\right)}{\sum_{k=A,R} \exp\left(V_{ij}^{k}\right)} \quad (8)$$

Thus, when X_{ij} is the total travel demand between zones i and j, the demand function of transport mode k would be:

$$x_{ijk} = P_{ij}^{k} X_{ij} = \frac{\exp\left(V_{ij}^{k}\right)}{\sum_{k=A,R} \exp\left(V_{ij}^{k}\right)} X_{ij} \quad (9)$$

$$P_{ij}^{A} = \frac{\exp\left(V_{ij}^{Air}\right)}{\exp\left(V_{ij}^{Air}\right)+\exp\left(V_{ij}^{Rail}\right)} = \frac{\exp\left(\theta_1^S q_{ij}^{A} + \theta_2^S\right)}{\exp\left(\theta_1^S q_{ij}^{A} + \theta_2^S\right)+\exp\left(\theta_1^S q_{ij}^{R}\right)} \quad (10)$$

$$q_{ij}^{R} = P_{ij}^{Linear}\cdot q_{ij}^{Linear} + P_{ij}^{Shinkansen}\cdot q_{ij}^{Shinkansen}$$

$$q_{ij}^{A} = w\cdot t_{ij}^{A} + p_{ij}^{A}$$

P_{ij}^{k}: Probability of choosing transport mode k between zones i and j

(k = A; air transport, k=R; railway)

V_{ij}^{k}: Utility when choosing transport mode k between zones i and j

q_{ij}^{R}: Log-sum value of railway from the Level Two model

4.4.2 Level Two

$$P_{ij}^{S} = \frac{\exp\left(V_{ij}^{S}/\lambda\right)}{\exp\left(V_{ij}^{S}/\lambda\right)+\exp\left(V_{ij}^{M}/\lambda\right)} = \frac{\exp\left(\theta_1^S q_{ij}^{S}/\lambda\right)}{\exp\left(\theta_1^S q_{ij}^{S}/\lambda\right)+\exp\left(\theta_1^S q_{ij}^{M}/\lambda\right)} \quad (11)$$

$$q_{ij}^{S} = wt_{ij}^{S} + p_{ij}^{S},\ q_{ij}^{M} = wt_{ij}^{L} + p_{ij}^{M}$$

P_{ij}^{S}, P_{ij}^{M}: Probability of choosing S (Shinkansen) or M (Maglev)

V_{ij}^{K}: Deterministic portion of utility when travelling by K ($K \in S, M$)

q_{ij}^{R}: Log sum of travelling by railway

λ: correlation factor between S and M

The nested logit model is used to reflect consumer preferences for Shinkansen and Maglev that are a closer substitute than air transport and railway in general. Thus, in the second stage of modal choice, λ is a parameter that gives the level of correlation between the two alternatives, Shinkansen and Maglev. The higher the λ the more the two choices are independent, and adding Maglev as an alternative is valued higher by tripmakers. Since we do not have observable data on the degree of independence between Shinkansen and Maglev, we shall use an exogenous value of 0.8 as λ.

4.5. Parameter estimation and exogenous values

Parameter estimation is conducted for the trip distribution model and modal split model. They are detailed in the Annex.

Price elasticity in the trip generator model is taken from past surveys. We use the following values. See Annex for a list of price elasticity values in past surveys.

Table 5. **Demand elasticity**

	Business	**Sightseeing**	**Private**
Price elasticity (β1)	0.7	1.5	1.5

Income elasticity in the trip generation model is also taken from past research. Income elasticity of 1.78 is used in the model based on Murakami *et al.* (2006). See Annex for a list of income elasticity values in past surveys.

4.6. Future setting of socio-economic factors and service characteristics of Maglev

4.6.1 Population and economic growth

Future estimates of population at city level are given by the National Institute of Population and Social Security Research. According to this estimate, the national population is expected to decrease from 127 million to 119 million; an approximately 6% decrease[6]. City level data aggregated to 207 zones indicate that while metropolitan areas such as Tokyo, Yokohama, Toyota (in the Nagoya region) and Amagasaki (in the Kansai region) increase their population, other areas suffer a decline.

As for economic growth, the current economic situation makes it difficult to specify robust economic prospects. Thus, we consider a number of scenarios with annual growth rates ranging from 0.5% to 3% in 0.5% intervals. The base year of the data set used in the model is 2005. The Maglev Super-Express inauguration year is set at 2025. A standard project duration of fifty years is used for the Maglev Super-Express so that the project is evaluated through the year 2075.

4.6.2 Service characteristics of Maglev

The following trip-time reduction and price increase between Tokyo-Nagoya and Tokyo-Osaka is used as a scenario for a future demand estimate.

Table 6. **Service characteristics of the Maglev Super-Express**

	Tokyo-Nagoya	**Tokyo-Osaka**
Time	40 minutes	60 minutes
Cost	1 000 yen increase	1 000 yen increase

Note: Twenty minutes are added at the transfer point when the Maglev Super-Express and other rail transport are used in a single journey.

4.6.3 OD zones that are affected by the introduction of Maglev

We need to assign OD zones that are affected by the introduction of Maglev. It is clear that OD pairs that are geographically irrelevant to the Tokyo-Nagoya-Osaka corridor need to be eliminated. Using NITAS, we identify OD pairs that currently take trips via Tokaido Shinkansen. Potential OD pairs that are currently not taking Tokaido Shinkansen but may choose Maglev once it is introduced are also included in the simulation.

4.6.4 Metropolitan zones

Three major metropolitan regions include the following prefectures. They comprise the metropolitan areas of Tokyo, Osaka and Nagoya, respectively.

Table 7. **Three metropolitan areas and prefectures**

	Tokyo Region	Hanshin Region	Chukyo Region
Prefecture	Tokyo-Kanagawa-Chiba-Saitama	Nara-Kyoto-Osaka-Hyogo	Aichi-Mie-Gifu

4.7. Result of the simulation

4.7.1 Impact of the Maglev Super-Express on modal split

Table 8 shows the estimated annual number of trips for the national total in 2025. Due to the decrease in population, benchmark figures without Maglev decrease by 2% compared to the 2005 population case. With the introduction of the Maglev Super-Express between Tokyo and Nagoya, the nation-wide modal split, for Shinkansen and Maglev combined, shifts from 75.6% to 76.1%. Table 9 depicts the estimated annual number of trips for the corridor between the Tokyo and Hanshin regions in 2025. There is a much larger impact in this corridor, the modal split for Shinkansen and Maglev combined changing from 78.6% to 81.4%. When the Maglev Super-Express connects Tokyo and Osaka via Nagoya, then 84.4% would be shared by Shinkansen and Maglev combined. Although introduction of the Maglev Super-Express does have a strong impact on air transport, more significant is the impact on Shinkansen. Indeed, more than half of Shinkansen trips will be taken away by Maglev in the corridor between the Tokyo and Hanshin regions.

Table 8. **Estimated annual number of trips (in millions) – national total in 2025**

	Air	Shinkansen	Maglev	Total
Without Maglev	84 (24.4%)	261 (75.6%)	- -	345
With Maglev Tokyo-Nagoya	83 (23.9%)	216 (62.6%)	46 (13.4%)	345
With Maglev Tokyo-Osaka	81 (23.4%)	200 (57.9%)	64 (18.6%)	346

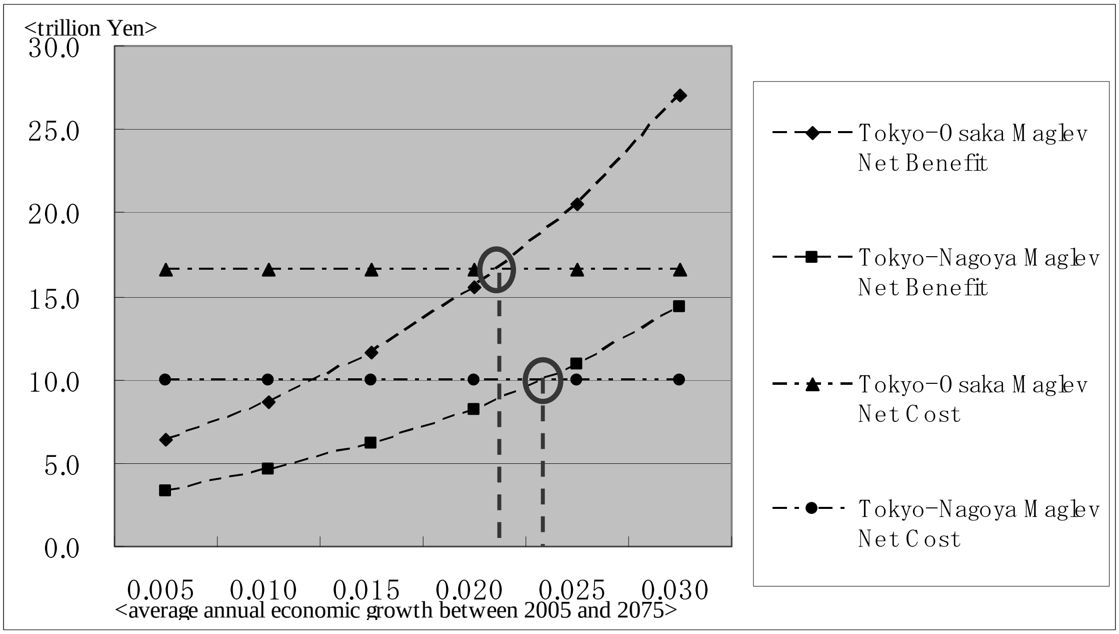
Table 9. **Estimated annual number of trips (in millions) – between Tokyo and Hanshin regions in 2025**

	Air	Shinkansen	Maglev	Total
Without Maglev	8 (21.4%)	31 (78.6%)	- -	39
With Maglev Tokyo=Nagoya	7 (18.6%)	13 (32.8%)	19 (48.7%)	40
With Maglev Tokyo=Osaka	6 (15.6%)	11 (26.4%)	24 (58.0%)	41

4.7.2 Benefits and costs of the Maglev Super-Express

The future benefits of introducing the Maglev Super-Express depend on the level of economic growth. We conducted a sensitivity analysis of net benefits with an annual growth rate ranging from 0.5% to 3% in 0.5% intervals. As for cost, we used data from a joint report by the Japan Railway Construction, Transport and Technology Agency (JRTT) and JR Central in July 2009, which revealed construction, maintenance and repair costs for the Tokyo-Nagoya Maglev Super-Express with a 50-year project duration[7]. It could be observed from Figure 16 that net benefit exceeds net cost when economic growth is above the 2.0% to 2.5% range. It should be noted that net benefit is calculated in comparison to the BAU case without any capacity constraint for Shinkansen or air transport. The net benefit will be greater if capacity constraint exists. With regard to annual economic growth, over 2% is a challenging target but not an inconceivable one. Future economic prospects, released by the Cabinet Office of Japan in January 2009, indicate a number of different GDP growth rate cases. Depending on the speed of recovery of the world economy, Japan is expected to grow at approximately 1.5% to 2% and above for the next decade. Demand growth from emerging economies such as China and India is promising. New opportunities in environmental business, nano-technology and robotics, among others, are expected to generate growth in the Japanese economy throughout the 21st century.

Figure 16. **Net benefit and cost of Maglev introduction (trillion yen)**



4.7.3 The impact of the Maglev Super-Express on CO_2 emissions

The environmentally friendly nature of Maglev technology should be noted. The CO_2 emission intensity of the Maglev Super-Express is one-third that of air transport. One of the expectations of introducing the Maglev Super-Express is its capability of mitigating CO_2 emissions from high-speed intercity transport. This, however, is not precisely the case. Because the Maglev Super-Express, with a CO_2 emission intensity five times higher than Shinkansen, would attract a considerable number of passengers, not only from air transport but also from Shinkansen, total CO_2 emissions from high-speed intercity transport would increase by 2.7% with the Maglev Super-Express between Tokyo-Nagoya and 4.9% between Tokyo-Osaka. If, however, the Shinkansen capacity constraint diverts considerable demand towards air transport, these estimates would need to be revised. We leave this question to future analysis. Also, there is a possibility that the increase in CO_2 from Shinkansen and Maglev could be mitigated by reducing the CO_2 content of the electric power supply. Due to the low utilisation of nuclear energy, the CO_2 content of electric power supplies in Japan is five times higher than that in France. There is potentially a large scope for substantial reductions in CO_2 emissions from this perspective.

5. CONCLUSION

In this paper we revisited the evolution of high-speed inter-city transport in Japan and conducted a simulation analysis of introducing the next-generation transport mode, the Maglev. In a unique market in which both high-speed railways, the Shinkansen and air transport developed simultaneously, modal choice based on price and speed has been manifested very clearly. So in assessing the impact of the Maglev Super-Express, planned to be introduced between Tokyo and Nagoya by 2025, we need to take into account the differences in price and speed characteristics of the existing and new transport modes.

From the simulation analysis, by a dynamic spatial nested logit model, we identify a significant opportunity for the Maglev Super-Express between Tokyo, Nagoya and Osaka. Accumulated social welfare and operational revenue, however, was found to exceed the net investment, maintenance and repair costs only when approximately 2%-3% annual economic growth is achieved for the next 65 years. If such economic conditions are realised, the total air transport market would also continue to grow, despite strong competition from the Shinkansen/Maglev system.

One other finding was Maglev's impact on CO_2 emissions. Maglev could not take advantage of its CO_2 emissions intensity being considerably lower than that of air transport. This is because Maglev attracts more passengers from Shinkansen, which has a five times lower CO_2 emissions intensity. An increase in total CO_2 emissions from electricity users, including the Maglev Super-Express, could be mitigated by the energy conversion sector's efforts to reduce the CO_2 content of electric power supplies through an increase in the utilisation ratio of nuclear energy, for instance.

More analysis is needed to unveil the full impact of high-speed inter-city transport improvements. In particular, we need to take capacity constraint into consideration. When economic growth triggers additional trips, capacity constraint in the existing Shinkansen network, for instance, may divert considerable demand to air transport. If this is the case, we need to alter the BAU case and reassess the net benefits and impact on CO_2 emissions. Furthermore, productivity gains, migration effects and national land-use efficiency are some of the themes that have not been covered by this paper. We look forward to further developments in such areas of research.

6. ACKNOWLEDGEMENTS

We express appreciation for research and support from the International Transport Policy Research Unit (ITPU), Graduate School of Public Policy, The University of Tokyo. We are also grateful to Kazuki Iwakami for his contributions to the data analyses and Tae Hoon Oum for his enthusiasm for intercity transport analysis.

NOTES

1. As of January 2001, the Ministry of Transport was integrated with the Ministry of Construction, etc., to form the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

2. 45/47 stands for 1970 and 1972 in Japan's Showa era.

3. In 1988, the name was changed to Japan Air Systems (JAS). In 2002 it was merged with JAL to form the current Japan Airlines Inc.

4. Apart from the two Class One airports, there are currently three others. New Tokyo International Airport, currently Narita International Airport, was constructed as a 100% government-owned agency, while Kansai International Airport, opened in 1994, and Chubu International Airport, opened in 2005, were PFIs.

5. Hereafter referred to as "Shinkansen".

6. Since there is no estimate for regional employees, we take the 2005 value as constant.

7. Tokyo-Osaka Maglev Super-Express costs were estimated by route length, since no official figures had been released as of July 2009. Both net benefit and net cost are present values at year 2025, depreciated by 4% per annum.

ANNEX

The estimation of parameters for trip distribution and the modal split model is conducted as follows.

1. Trip distribution model

1.1. Model to be estimated

The distribution model is in the following form. In order to derive the function to be estimated we give a benchmark destination J_i for every i. The relative probability of allocation of trips to destination j ($i \neq j$) *vis-à-vis* benchmark destination J_i, leaving out OD pairs without any trips, are pooled as samples.

$$\ln\left(\frac{P_{ij}^C}{P_{iJi}^C}\right) = V_{ij} - V_{iJi} = \theta_1^D q_{ij} + \theta_2^D \ln S_j - \theta_1^D q_{ij} - \theta_2^D \ln S_{Ji}$$

$$= \theta_1^D \left(q_{ij} - q_{iJi}\right) + \theta_2^D \left(\ln S_j - \ln S_{Ji}\right)$$

$$= \theta_1^D \left(q_{ij} - q_{iJi}\right) + \theta_2^D \left(\ln \frac{S_j}{S_{Ji}}\right)$$

Ji: a random benchmark destination from zone i ($j \neq Ji$

S_j: total trip destination to zone j

q_{ij}: log sum of trip between zones i and j

The distribution model is estimated by the weighted least squares method.

$$Y = \left\{\ln\left(\frac{P_{ij}^C}{P_{iJi}^C}\right)\right\} = \theta_1^D \left(q_{ij} - q_{iJi}\right) + \theta_2^D \ln\left(\frac{S_j}{S_{Ji}}\right)$$

$$\sqrt{w_i}Y = \sqrt{w_i}\left\{\ln\left(\frac{P_{ij}^C}{P_{iJi}^C}\right)\right\} = \sqrt{w_i}\theta_1^D \left(q_{ij} - q_{iJi}\right) + \sqrt{w_i}\theta_2^D \ln\left(\frac{S_j}{S_{Ji}}\right)$$

$\sqrt{w_i}$: squared root of trip generation at zone i

1.2. Description of data

Table 10. **List of data**

	Item	Definition of data	Source of data
Zone data	Population	Population of the zone	National Population Census (2005, MHLW)
	Employment	Number of employees in the zone	National Population Census (2005, MHLW)
	Trip attraction factor	Aggregate number of destination trips to the zone	Inter-regional Travel Survey (2005, MLIT)
Inter-zone data	Number of O-D trips	O-D trip between zones by major transport modes and purpose of travel	Inter-regional Travel Survey (2005, MLIT)
	OD travel time	Time of travel between zones	NITAS：National Integrated Transport Analysis System (2008, MLIT)
	OD travel cost	Fares paid for travel between zones (including access and egress)	Survey of Air Passengers (2005, MLIT), JTB timetable (2005, JTB)

1.3. Result of the parameter estimation

The result of the parameter estimation is shown in Table 11. Parameters are statistically significant and R^2 is at an acceptable level. The parameter for generalised cost (θ_1^D) is negative, as we had expected.

Table 11. **Trip distribution parameter**

Trip distribution parameter	Business		Tourism		Private	
	Parameter	t-ratio	Parameter	t-ratio	Parameter	t-ratio
Generalized cost(θ_1^D)	-0.294	-97.688	-0.286	-59.157	-0.361	-89.392
Trip attraction(θ_2^D)	0.765	122.545	0.703	75.642	0.551	66.505
R^2	0.684		0.531		0.642	
Sample size	11 334		7 194		7 732	

2. Modal split model

2.1. Model to be estimated

The probability of selecting air transport *vs.* rail could be expressed in the following form.

$$\frac{P_{ij}^{A}}{P_{ij}^{R}} = \frac{\dfrac{\exp(V_{ij}^{A})}{\exp(V_{ij}^{A})+\exp(V_{ij}^{R})}}{\dfrac{\exp(V_{ij}^{R})}{\exp(V_{ij}^{A})+\exp(V_{ij}^{R})}} = \frac{\exp(V_{ij}^{A})}{\exp(V_{ij}^{R})}$$

$$\ln\left(\frac{P_{ij}^{A}}{P_{ij}^{R}}\right) = \ln\left(\frac{P_{ij}^{A}}{1-P_{ij}^{A}}\right) = V_{ij}^{A} - V_{ij}^{R} = \theta_1^S (q_{ij}^{A} - q_{ij}^{R}) + \theta_2^S$$

A larger weight is placed for OD pairs with a high trip volume. We use the squared root of the total OD trips between zones ij (w_{ij}). θ_1^S should be negative since higher generalised costs reduce the incentive to choose that mode. Parameters θ_1^S, θ_2^S are estimated with the weighted least squares method.

$$\sqrt{w_{ij}}\ln\left(\frac{P_{ij}^{A}}{1-P_{ij}^{A}}\right) = \sqrt{w_{ij}}\theta_1^S (q_{ij}^{A} - q_{ij}^{R}) + \sqrt{w_{ij}}\theta_2^S$$

w_{ij}: total number of trips between zones i and j

$$q_{ij} = \frac{1}{\theta_1^S}\ln\left[\exp\left(\theta_1^S q_{ij}^{A} + \theta_2^S\right) + \exp\left(\theta_1^S q_{ij}^{R}\right)\right]$$

$$q_{ij}^{A} = p_{ij}^{A} + wt_{ij}^{A}、 q_{ij}^{R} = p_{ij}^{R} + wt_{ij}^{R}$$

q_{ij}^{A}: generalized cost of air transport, q_{ij}^{R}: generalized cost of railway

q_{ij}: expected generalized cost of travelling between zones i and j

w: value of time

2.2. Description of data

In addition to data used for estimating the trip distribution model, the following value of time factor from the existing literature is used to convert travel time into monetary value. This parameter is used by MLIT in its air transport demand model for airport planning in Japan and is estimated from disaggregate data on air transport passengers.

Table 12. **Value of time**

	Business	Sightseeing	Private
Time value in yen/hr	4 193	3 642	3 133
Time value in yen/min	69.88	60.70	52.22

2.3. Result of the parameter estimation

The result of the parameter estimation is listed in Table 13. Parameters are statistically significant. As we had expected, parameter θ_1^S is negative.

Table 13. **Modal split parameter**

Modal split parameter	Business		Tourism		Private	
	Parameter	t-ratio	Parameter	t-ratio	Parameter	t-ratio
Transport cost(θ1)	-1.433	-48.688	-0.846	-13.028	-1.113	-20.495
Constant(θ2)	-1.479	-27.462	-0.932	-11.259	-1.449	-24.511
R^2	0.699		0.303		0.487	
Sample size	1 670		588		955	

3. Price elasticity for trip generation model

Following is a list of major surveys of demand elasticity that were referenced.

Table 14. **Survey of demand elasticity**

		Leisure Travel	Business Travel
(i)	Air Passenger Travel (Cross-section)	1.52	1.15
	Intercity Rail Travel (Cross-section)	1.40	0.70
(ii)	Air Passenger Travel	1.10-2.70	0.40-1.60
	Intercity Rail Travel	1.40-1.60	0.60-0.70
(iii)	Air Passenger Travel (Short)	1.52	0.7

Sources:
(i) Oum, Waters and Yon (1992);
(ii) Oum, Waters and Yong (1990);
(iii) IATA and Inter VISTAS Consulting Inc. (2007).

4. Income elasticity for trip generation model

Following is a list of major surveys of income elasticity for the air transport market in Japan that were referenced.

Table 15. **Survey of income elasticity**

		Income elasticity
(i)	Ohashi *et al.* (2003)	1.50
(ii)	Yamaguchi (2005)	1.44
(iii)	Murakami *et al.* (2006)	1.78

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