High-speed inter-city transport system in Japan
- Past, present and the future -

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Mission of the paper

- Intercity transport system serves as a backbone of national economic geography.

- High-speed railway (+250km/h) and air transport are two major technologies of today’s high-speed intercity transport system.
Mission of the paper

- Looking ahead, next generation technology, the Maglev Super-express, is on the horizon.
- What is the nation-wide welfare impact and B/C of the Maglev? What is the relationship between B/C and economic growth? How about effect on GHG emissions?
Spatial Comparison of Europe and Japan

<table>
<thead>
<tr>
<th></th>
<th>Japan (milllion)</th>
<th>Spain</th>
<th>France</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>128</td>
<td>45</td>
<td>62</td>
<td>64</td>
</tr>
<tr>
<td>Area (1000km²)</td>
<td>378</td>
<td>505</td>
<td>552</td>
<td>243</td>
</tr>
<tr>
<td>GDP (billion US$)</td>
<td>4380</td>
<td>1437</td>
<td>2546</td>
<td>2768</td>
</tr>
</tbody>
</table>
As of 2009

Current Shinkansen Network

<table>
<thead>
<tr>
<th>In Operation (2,176km)</th>
<th>1,353 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Construction (634km)</td>
<td>397 miles</td>
</tr>
<tr>
<td>Planned (533km)</td>
<td>331 miles</td>
</tr>
</tbody>
</table>

- **Sanyo Shinkansen**: 334 miles (554km)
- **Joetsu Shinkansen**: 168 miles (270km)
- **Hokuriku Shinkansen**: 73 miles (117km)
- **Tohoku Shinkansen**: 369 miles (593km)
- **Tokaido Shinkansen**: 320 miles (515km)
- **Kyushu Shinkansen**: 79 miles (127km)

Key Richard dates:
- **1964**: Nagano
- **1972**: Okayama
- **1975**: Hakata
- **1982**: Osaka, Nagoya, Tokyo
- **1991**: Ueno
- **1994**: Shin-Yatsushiro
- **2002**: Hachinohe
- **2004**: Kagoshima-Chuo
# Main Features of the Shinkansen

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td>No passenger fatalities in the 44 years since 1964</td>
</tr>
<tr>
<td><strong>Punctuality</strong></td>
<td>Average delay time less than 1 minute (including the influence of natural disasters)</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>Capability of up to 14 departures per hour</td>
</tr>
<tr>
<td><strong>High Capacity</strong></td>
<td>More passengers per train set</td>
</tr>
<tr>
<td><strong>Environmentally Friendliness</strong></td>
<td>Less CO₂ emissions, less energy consumption</td>
</tr>
</tbody>
</table>
Current Situation of Domestic Air Transport in Japan (Network Structure)

Width of the blue line depicts annual number of passengers. 26 domestic routes exceeding one million passenger per year, are shown.

※ Only major Airports are listed
※ Size of the circle depicts the passenger volume of airports

Source: Civil Aviation Bureau, MLIT
Airports capable of accommodating turbo-jet aircrafts (7)

Shinkansen (553km)

Source: Mapped with MLIT data.
Source: Mapped with MLIT data.
Trend in Demand (paxkm) of Shinkansen and air

Source: MLIT data and Cabinet Office data compiled.
Income elasticity: 1.44 ~ 1.78

Price elasticity: -0.7 ~ 1.5

Source: MLIT data and Cabinet Office data compiled.

*Shinkansen/Airfare index is calculated by weighted average of each fare level and CPI adjusted.

(1965 = 100)
Recent trend in Shinkansen and air ridership and fare index, and GDP growth

Source: MLIT data, Cabinet Office data, Bank of Japan data complied.
April-June 2009 figures are tentative.
Relative price of Shinkansen and air transport is one of the determinants of modal split.
The distance zone that railways demonstrate its competitiveness most: **300-450 miles (travel time: 2-4 hrs.)**
Share of the Shinkansen and Air Transportation

Sanyo Shinkansen
(344 miles)

Tokaido Shinkansen
(320 miles)

Tokyo
Nagoya
Shin-Osaka
Hiroshima
Okayama
Hakata

Number of Passengers/day

Tokyo
Nagoya
Osaka
Okayama
Hiroshima
Hakata

0 mile
212 miles
320 miles
420 miles
510 miles
664 miles

Source: Market share is the percentage of all railway and airline services based on the inter-prefectural data of the Inter-Regional Passenger Mobility Survey (FY 2005), published by the MLIT.
Let $U_k$ be utility of choosing transport mode $k$ composed of deterministic portion $V_k$ and random portion $\delta$ so that, $U_k = V_k + \delta$

Let $V_k$ be a function of service characteristics ("price" in this case) and defined as follows.

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

where $p_k$: fare of mode $k$ and $\alpha, \beta$: parameters.

Suppose there are two modes; railway (R) and air transport (A).

Probability of choosing railway or air transport would be,

$$P_R = \frac{\exp(V_R)}{\exp(V_R) + \exp(V_A)}$$

and

$$P_A = \frac{\exp(V_A)}{\exp(V_R) + \exp(V_A)}$$
Let $X$ be total demand between a specific OD.

Then, demand for railway $X_R$ and air transport $X_A$ would be

$$X_R = s_R X = P_R X \quad X_A = s_A X = P_A X$$

Then,

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

Natural log of both sides yields a formula to be estimated:

$$\ln\left(\frac{X_A}{X_R}\right) = \ln\left(\frac{P_A}{P_R}\right) = \alpha + \beta(p_A - p_R) + \varepsilon$$

where $\varepsilon$ is the error term.
### Parameter estimate using pooled historical data

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Data set A (paxkm)</th>
<th>Data set B (pax +300km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>t-stats</td>
</tr>
<tr>
<td>Constant ($\alpha$)</td>
<td>0.070</td>
<td>1.194</td>
</tr>
<tr>
<td>Transport Cost ($\beta$)</td>
<td>-1.242</td>
<td>-11.804*</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.699</td>
<td></td>
</tr>
<tr>
<td>Sample Size</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Own price elasticity of rail (average)</td>
<td>$</td>
<td>\beta p_R (1 - s_R)</td>
</tr>
<tr>
<td>Cross price elasticity of rail (average)</td>
<td>$</td>
<td>\beta p_R s_R</td>
</tr>
</tbody>
</table>
Maglev Super-express

In 2007, JR Central announced its intentions to construct Maglev Super-express between Tokyo=Nagoya by 2025. Currently, government consultation is being conducted.

Recorded 581km/h
Comparison of Air Transport, Maglev and Shinkansen

CO₂

125

43

14

g-CO₂/passenger kilometer

Cruising Speed km/h

Speed

800+

500+

300+
Model structure

207 zones

Population  Employees

① Trip generation

② Trip distribution

③ Modal split

Air  Railway

④ Railway modal split

Shinkansen & other railway  Maglev
207 Zones
Service specification of Shinkansen, Maglev and air transport

<table>
<thead>
<tr>
<th></th>
<th>Tokyo＝Nagoya (366km)</th>
<th>Tokyo＝Osaka (553km)</th>
<th>CO₂Inte nsity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (min)</td>
<td>Fare (Yen)</td>
<td>CO₂/p ax</td>
</tr>
<tr>
<td>Shinkansen</td>
<td>103</td>
<td>10,780</td>
<td>5.2kg</td>
</tr>
<tr>
<td>Maglev</td>
<td>40</td>
<td>11,780</td>
<td>15.7kg</td>
</tr>
<tr>
<td>Air transport</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Simulation Results  【National Total】
- In Year 2025 -  (Unit: million pax)

Note: zero GDP growth case
Simulation Results 【Tokyo = Osaka】
- In Year 2025 - (Unit: million pax)

39

3  1  8
Shinkansen  Air transport

41

1  1  4  6
Shinkansen  Maglev: Tokyo=Osaka  Air transport

27% Increase in CO₂

Note: zero GDP growth case
Simulation Results - In Year 2025 -

( Unit: million pax )

<table>
<thead>
<tr>
<th></th>
<th>Air transport</th>
<th>Shinkansen</th>
<th>Maglev</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National ttl</td>
<td>Tokyo = Osaka</td>
<td>National ttl</td>
<td>Tokyo = Osaka</td>
</tr>
<tr>
<td>BAU (no Maglev)</td>
<td>84 (24.4%)</td>
<td>8 (21.4%)</td>
<td>261 (75.6%)</td>
<td>31 (78.6%)</td>
</tr>
<tr>
<td>Tokyo=Nagoya Maglev</td>
<td>83 (23.9%)</td>
<td>7 (18.6%)</td>
<td>216 (62.6%)</td>
<td>13 (32.8%)</td>
</tr>
<tr>
<td>Tokyo=Osaka Maglev</td>
<td>81 (23.4%)</td>
<td>6 (15.6%)</td>
<td>200 (57.9%)</td>
<td>11 (26.4%)</td>
</tr>
</tbody>
</table>
Simulation Results

【Relationship between GDP growth and B/C】

Average GDP growth rate from 2005 to 2075
Discounted at 4% per annum
Economic growth and social discount rate

\[ s_G = g^e + d \]

- \( g \): GDP per capita growth rate
- \( e \): inter-temporal coefficient \((=1.0)\)
- \( d \): constant discount rate \((=1.0\%)\)

Simulation Results

【Relationship between GDP growth and B/C】

Average GDP growth rate from 2005 to 2075
Discounted at GDP growth rate +1% per annum
CO₂ intensity of electricity

<table>
<thead>
<tr>
<th>Country</th>
<th>CO₂ intensity (kg-CO₂/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>0.09</td>
</tr>
<tr>
<td>Canada</td>
<td>0.20</td>
</tr>
<tr>
<td>Japan</td>
<td>0.48</td>
</tr>
<tr>
<td>Germany</td>
<td>0.50</td>
</tr>
<tr>
<td>USA</td>
<td>0.58</td>
</tr>
</tbody>
</table>
Nuclear and water energy ratio of power supply in major countries

- **France**:
  - Nuclear: 83%
  - Water: 10%

- **Canada**:
  - Nuclear: 59%
  - Water: 15%

- **Japan**:
  - Nuclear: 31%
  - Water: 9%

- **Germany**:
  - Nuclear: 31%
  - Water: 7%

- **USA**:
  - Nuclear: 21%
  - Water: 7%
Annual average GDP growth (1996→2006)

Source: Mapped from Cabinet Office data.
City hierarchy in Japan

Railway Accessibility Cartogram

Area-Population Cartogram

Source: Ryo Inoue, Shimizu Lab., University of Tokyo
Conclusions

- Growth of demand for high-speed intercity transport is sensitive to income (GDP) and service level (price, speed, etc.).
- From cross-section perspective, price and speed affects modal-split between Shinkansen and air transport.
- From simulation analysis with 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 cost only when approximately 2% - 2.5% annual economic growth is achieved for the next 65 years.

If such economic condition is realized, total air transport market would also continue to grow despite strong competition from the Shinkansen/Maglev system.
Another finding was Maglev’s impact on CO$_2$ emission.

Because Maglev attracts more passengers from Shinkansen that has three times lower CO$_2$ emission intensity, total CO$_2$ emission increases with the introduction of Maglev.

Increase in total CO$_2$ emission from electricity users could be mitigated by reduction of CO$_2$ content of electric power supply through increase in utilization ratio of nuclear energy etc.
Further analysis is needed to unveil the full impact of high-speed intercity transport improvement.

In particular, we need to take capacity constraint into consideration.

When economic growth triggers additional trips, capacity constraint in existing Shinkansen network may divert considerable demand to air transport.

If this is the case we need to alter the BAU case and reassess net benefit and impact on CO$_2$ emissions.
Decrease in intercity transport cost may accelerate agglomeration at the national and East Asian level.

Productivity gains, migration effects and national land-use efficiency are some of the themes that have not been covered by this paper. These issues are left for future research.
Thank you for your attention