Improvement of Convenience and Change in CO$_2$ Emission by Development of High Mobility Networks in Japan

-Analysis of Air, Railways and Road Networks from 1960 to 2000-

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Abstract: The development of high quality efficient national transport networks is required in Japan. At the same time, we cannot disregard the environmental load of such national transport systems. In this study, improvement of convenience and change in CO$_2$ emission by the development of high mobility networks consisting of air, railways and road networks are analyzed quantitatively from 1960 to 2000. The change in convenience of high mobility networks is analyzed using the index of generalized cost. Also, we calculated and analyzed the amount of CO$_2$ emission by high mobility networks. In the comparison analysis between improvement of convenience and change in CO$_2$ emission by development of high mobility networks, it was found that improvement of convenience by development of high mobility networks influenced increase in CO$_2$ emission remarkably.

Key Words: High mobility networks, Improvement of convenience, CO$_2$ emission

1. INTRODUCTION

1.1 Aim of Study
In recent years, we have been facing serious problems concerning decrease in population in Japan. In addition, the budget for investment of transport network development in national land has been reduced. In such a situation, the development of both high quality and efficient national transport networks is required.

The Japanese Government announced the “National Land Sustainability Plan” presented by The Ministry of Land Infrastructure and Transport in 2007. It is described in this plan that it is necessary to develop strategic high mobility networks corresponding to diverse economic activities. Also stressed in the report is the importance of developing high quality national transport networks which take into consideration the best use of existing systems and promote efficient investment.
In the present day both in Japan and all over the world, people cannot disregard environmental problems. In particular, the environmental load emitted by national transport systems has increased. Volume of emissions has increased as the national transport networks have been developed. Environmental load has a bad influence with increase in use of transport systems. Development of transport systems tends to increase frequency of travel. Accordingly, when the national transport systems are developed, the good influence by improvement of convenience as well as the bad influence by increasing environmental load should be considered in depth.

Therefore, in this study, improvement of convenience and change in CO$_2$ emission by the development of high mobility networks consisting of air, railways and road networks in Japan are analyzed quantitatively from 1960 to 2000. In the analysis, travel cost, travel time and generalized cost are used as indexes for clarifying the improvement of convenience for every 10 years from 1960 to 2000. Change in CO$_2$ emission is also measured for every 10 years. Finally, the relationship between improvement of convenience and change in CO$_2$ emission is discussed.

1.2 Previous Studies
There have been a number of studies related to the analysis of development of transport networks in Japan. For instance, Nakagawa et al. (1994) pointed out that the relationship between development of transport networks and influence of such development on cities and regions was not investigated clearly before. Then, they discussed methodology to measure the possibility of interaction between regions by the development of transport networks. Moreover, they measured the extended possibility of interaction between regions from 1898 to 1990 using time people can stay in cities and time for accessibility. Miura (2004) applied Huff’s Model to estimate the number of travelers between regions in Japan. He also proposed a method of analysis employing sensitivity analysis in order to estimate influence of reduction of travel time due to development of transport facilities on the number of travelers who visit certain regions. Kondo et al. (1996) analyzed change in development of high mobility networks based on users benefit from 1960 to 1990, and evaluated service level of transport modes using a ratio of cost increase to reduced travel time.

There are several studies concerned with analysis of environmental load. Oneyama et al. (1997) calculated amount of CO$_2$ emission from transport networks in several cities of Japan, and analyzed the influence of structure of city on environmental load emitted in the city. Chikanari et al. (2003) proposed a method to estimate the number of trips of various transport modes for the purpose of minimization of energy consumption from transportation and level of mobility in certain region, and applied it to Keihanshin metropolitan areas in Japan. Kojima et al. (2004) developed a model that can be used for evaluation of environmental load due to structure of a city and transport policy.

There have been a number of studies related to the theme of this study. However, we were unable to find any study which addresses change in CO$_2$ emission depending on transport modes over the entire nation covering a long period of time. The relationship between the improvement of convenience and change in CO$_2$ emission has also not been analyzed to date. When we analyze the problems described above, valuable information can be obtained for design and development planning of future transport networks in consideration of the environment. This is the main aim of the present study.
2. TRANSPORT NETWORKS AND DATA

2.1 Transport Networks
The transport networks analyzed in this study consist of three transport modes. Namely; air, railways and road networks. With the exception of sea transportation which accounts for small percentage of the total, almost all trips by people in Japan use the above-mentioned three modes. Therefore, we choose these three networks as major modes. At the same time, we consider that the improvement of convenience and change in CO₂ emission by the development of high mobility networks in Japan can be analyzed using these three networks. The railways networks analyzed in this study consist of only railways lines in Japan, and the road networks consist of only roads. However, the networks consisting of airlines, railways lines and roads are called as air networks in this study.

2.2 Analysis Period
The analysis period of this study spanned forty years from 1960 to 2000. In this period of time, high mobility networks developed rapidly in Japan. Figure 1 shows the change of the number of flights in air networks in Japan. Figure 2 shows the development of the length of Shinkansen lines in railways networks, and figure 3 illustrates the development of the length of expressway in road networks. As these figures show, the transportation facilities have been improved remarkably in the latter half of the 20th Century.

Figure 1 Development of air networks (Number of flights)

Figure 2 Development of railways networks (Length of Shinkansen lines)
2.3 Regions
47 prefectures with the exception of Okinawa prefecture in Japan are chosen as unit regions of analysis. Okinawa prefecture is a small group of islands that is not connected by the bridge with other main islands of Japan. Therefore, Okinawa prefecture is not included in regions for analysis.

2.4 Data of Transport
Data concerning the service level of transport consists of travel cost and time between prefectures along the shortest route in terms of travel time. Places of origin and destination to measure the travel time between prefectures are those where their capital cities are located. Travel cost and time in air networks are measured using airlines’ timetables. The cost and time needed for access from the origin to the airport and for egress from the airport to the destination are measured in road maps and train timetables. Travel cost and time in railways networks can be measured using the train timetables. And, travel cost and time spent on road networks are measured using data from the NITAS and road maps. The NITAS shows travel cost and time for the shortest route in time (not distance) between prefectures in 2000. Travel cost and time in 1960, 1970, 1980 and 1990 are measured from maps in which road networks are illustrated referring data of NITAS. Travel cost for each year of analysis is converted into the value of the year 2000 using a deflation index.

As for population of prefectures, data from the National Population Census is used. As for the number of people who travel between prefectures by the three transport modes, data from the Report of the Traveler Movement of between Regions is used.

3. IMPROVEMENT OF CONVENIENCE BY DEVELOPMENT OF HIGH MOBILITY NETWORKS

3.1 Method of Analysis
In this study, improvement of convenience as a result of development of high mobility networks is analyzed using travel cost and time.

Firstly, travel cost and travel time between prefectures for the three transport modes are measured when one person who lives in each prefecture travels. We suppose two cases about
ways of travel. It is supposed in [Case 1] that the person living in any prefecture visits all prefectures only one time. In [Case 2] it is assumed that the person visits all prefectures, and the number of visits is in proportion to population of the prefectures the person visits. Travel cost and time of these two cases are calculated from 1960 to 2000 by three transport modes using equations (1) ~ (4). As mentioned above, the fundamental concept in this study is to evaluate the convenience of transport networks based on use of transportation facilities. Here, travel cost and time are calculated under the condition that all people living in any prefecture are given the same opportunities to travel.

[Case 1]

Travel Cost
\[ c^k_1 = \frac{\sum_i \left( \frac{\sum_j c^k_{ij}}{\sum_j d_{ij}} \right)}{n} \]  

Travel Time
\[ t^k_1 = \frac{\sum_i \left( \frac{\sum_j t^k_{ij}}{\sum_j d_{ij}} \right)}{n} \]

[Case 2]

Travel Cost
\[ c^k_2 = \frac{\sum_i \left( \frac{\sum_j P_j c^k_{ij}}{\sum_j P_j d_{ij}} \right)}{n} \]

Travel Time
\[ t^k_2 = \frac{\sum_i \left( \frac{\sum_j P_j t^k_{ij}}{\sum_j P_j d_{ij}} \right)}{n} \]

As equations (1) ~ (4) show, travel cost \( c_1 \) and \( c_2 \), as well as travel time, \( t_1 \) and \( t_2 \), are values per unit distance. The reasons why these values are expressed per unit distance are explained as follows. First, it is easy to understand travel cost and time per unit distance when they are compared for 10-year periods. Second, if travel cost and time are not divided by unit distance, prefectures located in central Japan have relatively small values. On the contrary, prefectures located in the north and south have relatively big values. Therefore, in this study, \( c_1, c_2, t_1 \) and \( t_2 \) are calculated as the average values of all prefectures in Japan.

The generalized cost of travel is defined as a compound function with travel cost and time based on the value of time of people. Improvement of convenience in use of transportation for people in Japan is considered to be measured using the generalized cost. Generalized cost is
expressed by equations (5) and (6).

[Case 1]
Generalized Cost $G_1^k = c_1^k + \mu t_1^k$ (5)

[Case 2]
Generalized Cost $G_2^k = c_2^k + \mu t_2^k$ (6)

\[
\mu : \text{Value of time}
\]

3.2 Change in Travel Cost

Table 1 Change in travel cost

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
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</thead>
<tbody>
<tr>
<td>Air (yen/km)</td>
<td>101.71</td>
<td>69.07</td>
<td>61.53</td>
<td>53.54</td>
<td>54.54</td>
</tr>
<tr>
<td>Railway (yen/km)</td>
<td>29.18</td>
<td>25.95</td>
<td>27.81</td>
<td>38.66</td>
<td>37.56</td>
</tr>
<tr>
<td>Road (yen/km)</td>
<td>40.53</td>
<td>26.00</td>
<td>30.25</td>
<td>29.69</td>
<td>26.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air (yen/km)</td>
<td>98.70</td>
<td>65.88</td>
<td>58.18</td>
<td>50.00</td>
<td>50.10</td>
</tr>
<tr>
<td>Railway (yen/km)</td>
<td>28.51</td>
<td>26.18</td>
<td>27.90</td>
<td>37.94</td>
<td>36.46</td>
</tr>
<tr>
<td>Road (yen/km)</td>
<td>40.01</td>
<td>25.97</td>
<td>30.91</td>
<td>29.41</td>
<td>26.26</td>
</tr>
</tbody>
</table>

Table 1 shows change in travel cost of [Case 1] and [Case 2]. The values of travel cost in [Case 1] and [Case 2] are similar but those of [Case 1] are a little bigger than those of [Case 2]. This means that average travel cost when people visit all prefectures only one time is a little higher than that when people visit all prefectures in proportion to their population. The cost of air travel is the highest of three modes in every year. The cost of railways increase from 1970 to 1990, and that of 1990 and 2000 are almost same. The cost of road is the cheapest in 1990 and 2000.

3.3 Change in Travel Time

Table 2 Change in travel time

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
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</thead>
<tbody>
<tr>
<td>Air (min/km)</td>
<td>0.769</td>
<td>0.722</td>
<td>0.622</td>
<td>0.564</td>
<td>0.543</td>
</tr>
<tr>
<td>Railway (min/km)</td>
<td>1.677</td>
<td>1.189</td>
<td>1.046</td>
<td>0.876</td>
<td>0.828</td>
</tr>
<tr>
<td>Road (min/km)</td>
<td>1.106</td>
<td>0.977</td>
<td>0.774</td>
<td>0.674</td>
<td>0.609</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air (min/km)</td>
<td>0.717</td>
<td>0.678</td>
<td>0.582</td>
<td>0.532</td>
<td>0.505</td>
</tr>
<tr>
<td>Railway (min/km)</td>
<td>1.617</td>
<td>1.143</td>
<td>1.007</td>
<td>0.833</td>
<td>0.796</td>
</tr>
<tr>
<td>Road (min/km)</td>
<td>1.112</td>
<td>0.956</td>
<td>0.747</td>
<td>0.659</td>
<td>0.608</td>
</tr>
</tbody>
</table>
Table 2 shows the change in travel time from 1960 to 2000. When the values of travel time in [Case 1] and [Case 2] are looked at, it can be seen that they show the same tendency as the values of travel cost in Table 1 show. Travel time of every transport mode has become shorter year by year. In particular, the change of travel time of railways from 1960 to 1970 is remarkable. This shows the contribution of development of railways networks by the introduction of Shinkansen.

3.4 Value of Time

In the estimation of value of time, the income method is applied. The average value of time is estimated using the annual income and working time. Equation (7) is used for estimation of the value of time.

\[
\mu = \frac{I(w_m \times M + w_f \times F)}{P}
\]

where:
- \( I \) : Average annual income
- \( w_m \) : Work time of males
- \( w_f \) : Work time of females
- \( M \) : Population of males
- \( F \) : Population of females
- \( P \) : Total population

The value of time is estimated for each prefecture, first. Then, the average value of time for Japan is calculated. Results of the estimation of time value for Japan are shown in Figure 4 and Figure 5. Figure 4 shows change in the nominal value of time, and Figure 5 shows the real value of time for the value of 2000 which is converted from the nominal value of time by a deflation index in the year 2000.

![Figure 4 Average value of time (nominal)](image)

![Figure 5 Average value of time (real)](image)

Figure 4 shows that the nominal value of time has increased year by year. However, the real value of time has been irregular. The value of time in 2000 shows a high value.

3.5 Change in Generalized Cost

Changes in generalized costs of [Case 1] and [Case 2] are illustrated in Figures 6, 7 and 8. These figures show generalized costs measured by real values.

Generalized cost per unit distance has decreased from 1960 to 2000. However, generalized
cost of railways increased a little from 1990 to 2000, because of the increase of railways fares due to privatization of Japanese National Railways in 1987.

Figure 6 Change in generalized cost (Air : Real)

Figure 7 Change in generalized cost (Railways : Real)

Figure 8 Change in generalized cost (Road : Real)
4. CHANGE IN CO₂ EMISSION BY DEVELOPMENT OF HIGH MOBILITY NETWORKS

4.1 Method of Analysis
In this section, a method to estimate amount of CO₂ emission from high mobility networks is explained.

4.1.1 CO₂ Emission by Air Networks
Amount of CO₂ emission by air mode is calculated using equation (8).

\[
CO_2^{\text{air}} = \alpha^{\text{air}} \sum_k A_k^{\text{air}} \times N_k^{\text{air}} \times F^{\text{air}}
\]

\( \begin{align*}
CO_2^{\text{air}} & : \text{Amount of CO}_2 \text{ emission by air mode} \\
F^{\text{air}} & : \text{Consumption of aircraft fuel per unit distance} \\
A_k^{\text{air}} & : \text{Distance of air route } k \\
N_k^{\text{air}} & : \text{Frequency of flights in air route } k \\
\alpha^{\text{air}} & : \text{Coefficient of convention of aircraft fuel into CO}_2 \text{ for air mode}
\end{align*} \)

The consumption of aircraft fuel includes both jet fuel and gasoline fuel, but in this study, we suppose only jet fuel is used because the gasoline fuel is used about 1% of all fuel in amount.

4.1.2 CO₂ Emission by Railways Networks
Amount of CO₂ emission by railways is calculated using equation (9).

\[
CO_2^{\text{rail}} = \alpha^{\text{rail}} \sum_i \sum_j D_{ij}^{\text{rail}} \times X_{ij}^{\text{rail}}
\]

\( \begin{align*}
CO_2^{\text{rail}} & : \text{Amount of CO}_2 \text{ emission by railways} \\
D_{ij}^{\text{rail}} & : \text{Distance between prefectures } i \text{ and } j \text{ by railways} \\
X_{ij}^{\text{rail}} & : \text{Number of people traveling between prefectures } i \text{ and } j \text{ by railways} \\
\alpha^{\text{rail}} & : \text{Coefficient of convention into CO}_2 \text{ emission for railways}
\end{align*} \)

The distance between prefectures i and j by railways is measured along railways lines. The coefficient of convention for converting total distance of travel by all passengers into the amount of CO₂ emission for railways is consulted in the report of the Ministry of Land, Infrastructure and Transport (2007).

4.1.3 CO₂ Emission by Road Networks
The amount of CO₂ emission by road transport is calculated using equation (10).

\[
CO_2^{\text{car}} = \alpha^{\text{car}} \sum_i \sum_j D_{ij}^{\text{car}} \times X_{ij}^{\text{car}}
\]

\( \begin{align*}
CO_2^{\text{car}} & : \text{Amount of CO}_2 \text{ emission by road transport} \\
D_{ij}^{\text{car}} & : \text{Distance of the shortest route between prefectures } i \text{ and } j \text{ on road transport} \\
X_{ij}^{\text{car}} & : \text{Number of people traveling between prefectures } i \text{ and } j \text{ on road transport} \\
\alpha^{\text{car}} & : \text{Coefficient of convention into CO}_2 \text{ emission for road transport}
\end{align*} \)
The shortest routes between prefectures i and j on road networks in 2000 were determined from data of NITAS. The shortest routes on road networks in 1960, 1970, 1980 and 1990 are measured on maps in which road networks are illustrated referring to data of NITAS. The coefficient of convention for converting total distance of travel by all passengers into amount of CO₂ emission for road transport is consulted in the report of the Ministry of Land, Infrastructure and Transport (2007).

4.2 Results of Analysis
Amount of CO₂ emission by high mobility networks from 1960 to 2000 is calculated. This is shown in Table 3 and their changes are illustrated in Figure 9 and Figure 10. Figure 9 shows change in amount of CO₂ emission of calculated values. Figure 10 shows change in amount of CO₂ emission with the index to convert values for the year of 1960 into 1.

As these figures show, amount of CO₂ emission has increased year by year. When Figure 9 is looked at, it is clear that the amount of CO₂ emission by road networks is big and the proportion of that in three transport modes is more than 70 percents. When the rate of change in amount of CO₂ emission is observed in Figure 10, it can be seen that amount of CO₂ emission by air networks and road networks have increased remarkably with almost same rate. The growth rate of CO₂ emission by railways is lower in comparison with that of air and road modes.

Table 3 Change in CO₂ emission (t-CO₂)

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<tbody>
<tr>
<td>Air</td>
<td>981,202</td>
<td>3,015,736</td>
<td>5,266,305</td>
<td>6,764,328</td>
<td>10,362,879</td>
</tr>
<tr>
<td>Railway</td>
<td>8,629,678</td>
<td>9,903,712</td>
<td>10,474,746</td>
<td>12,430,903</td>
<td>12,189,625</td>
</tr>
<tr>
<td>Road</td>
<td>54,493,974</td>
<td>134,581,193</td>
<td>294,176,641</td>
<td>332,206,896</td>
<td>381,025,766</td>
</tr>
</tbody>
</table>

As these figures show, amount of CO₂ emission has increased year by year. When Figure 9 is looked at, it is clear that the amount of CO₂ emission by road networks is big and the proportion of that in three transport modes is more than 70 percents. When the rate of change in amount of CO₂ emission is observed in Figure 10, it can be seen that amount of CO₂ emission by air networks and road networks have increased remarkably with almost same rate. The growth rate of CO₂ emission by railways is lower in comparison with that of air and road modes.

Figure 9 Change in CO₂ emission (Calculated values)
Figure 10 Change in CO$_2$ emission (Index)

5. COMPARISON ANALYSIS BETWEEN IMPROVEMENT OF CONVENIENCE AND CHANGE IN CO$_2$ EMISSION

In this chapter, the relationship between improvement of convenience and change in CO$_2$ emission is discussed. Figures 11, 12 and 13 show the relationship between them. In these figures, as an index to explain the improvement of convenience, number of flights is adopted in air networks. As indexes to explain improvement of convenience, the length of Shinkansen in railways networks and length of expressways in road networks are used.

As these figures show, in the three transport modes, amounts of CO$_2$ emission have increased in proportion to development of the networks. These figures prove that the improvement of convenience promoted by development of transportation facilities have strongly influenced increase in amount of CO$_2$ emission by transport modes.

Figure 11 Change in number of flights and CO$_2$ emission
6. CONCLUSION

In this paper, change in convenience of high mobility networks in Japan was analyzed using travel cost, travel time and generalized cost in every 10 years from 1960 to 2000. In addition, we calculated and analyzed amount of CO₂ emission produced by high mobility networks from 1960 to 2000. Then, the relationship between improvement of convenience and change in CO₂ emission was discussed.

The main results obtained in this study are presented as follows. From the analysis of change in generalized costs, we confirmed that they decreased generally in three transport modes from 1960 to 2000. By the analysis of change of CO₂ emission, amounts of emission have increased in three transport modes, and especially, the amount of CO₂ emission by road networks has been quite big rather than that by air networks and by railways networks.
Finally, in the comparison analysis between improvement of convenience and change in CO₂ emission as a result of development of high mobility networks, it was found that the improvement of convenience promoted by development of transportation facilities has had a strong influence on increase in amounts of CO₂ emission by the three transport modes looked at in this paper.

It was clarified that, in terms of CO₂ emission, its amount by railways is small. Regarding this, it can be said that railways networks with Shinkansen lines have an advantage in the environment. Air networks have another advantage to move people very quickly. In the future, we need to consider a plan to develop high mobility networks over the national land paying attention to advantage of transport modes with special consideration of their environmental impact.

REFERENCES

Ministry of Land, Infrastructure and Transport. (2007) National Land Sustainability Plan,
Ministry of Land, Infrastructure and Transport, Tokyo.