Which Country's Expressway Network Has been Better Developed?
A Methodology of Macroscopic International Comparison under Geographic, Demographic and Economic Differences

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Abstract: A scientific methodology specified by Normalized Development Level (NDL) for international comparison of the accessibility in expressway network is developed with consideration of the difference of countries in their area, population, economic development level, geographical conditions including seismic risk, which is applied to time series data of various countries over the world including EASTS’ member states. Furthermore, an index to measure the regional balance of expressway development: Regional Balance Index (RBI) is also proposed based on the calculated results of NDL and applied to the time series data in Japan, US and EU. This comparison approach based on a simplified theory which can be widely applicable even for countries and regions with limited data-availability seems practically useful for evaluating of current situations in different countries, different regions, and different times comparatively, for reviewing history of development, and for discussing direction of long-term development policy of expressway network for the future.

Keywords: expressway network, development level, international comparison,

1. INTRODUCTION

It is an important and reasonable request in the macroscopic planning stage of an infrastructure to find an answer to the question: how should be the suitable quantitative or qualitative level of the infrastructure such as expressway network in a country or in a region? One of the methodological approaches to this question is Cost-Benefit Analysis which is often used in the economic evaluation of individual infrastructure investment projects. However, it has not yet been applied to such macroscopic problems such as nationwide expressway network planning or countrywide road investment policy as the whole maybe due to its not-a-few practical limitations.

Another approach to such questions is to make better political decision by finding the relative position of the level of infrastructure of a nation or a region through international or inter-regional comparison. Such understandable “relative evaluation” might be more fitted
than “absolute evaluation” of Cost Benefit Analysis in the macroscopic evaluation of infrastructure in which the consensus of politicians and people is especially required.

However, we have to pay deep attention to scientific and theoretical suitability in a methodology of comparison when a “relative evaluation” approach is adopted. As the matter of fact, un-scientific international comparison has often been implemented with some particular political tendency. For example, Weekly Diamond (2009) adopted the length of expressway network per unit habitable area of a county as an index of international comparison, and claimed the level of expressway network of Japan was already too much constructed. On the contrary, Japanese Ministry of Land, Infrastructure and Transport (2004) compared the length of expressway per number of automobile, and stated that the network is still insufficient.

More scientific method of international comparison of the level of development in expressway network has been tried in IEDA (2005) and in TAKEBE (2010a and 2010b), both of which were based on the idea of “Land Characteristic Index” which was firstly introduced in Japanese Ministry of Construction in 1970s. IEDA and IGO (2010) re-formulated and generalized the idea mathematically and developed “Normalized Development Level” (NDL) to position a country or a region in an international context, and “Regional Balance Index” (RBI) to identify inter-regional situation of balance or disparity.

This paper further generally developed the normalization/ comparison method of IEDA and IGO (2010) by considering the geographic and geo-economic differences of countries, and applied it for the international comparison of expressway network of various countries including Asian states.

2. FORMULATION AND PREPARATION

2.1 Formulation of problem

Suppose expressway network of the length L is constructed in a country with area A and population P. If the network is expanded, the accessibility to the network increases while the cost for construction and management of the network also increases. There must be a suitable level of expressway network being dependent on demographic, economic, and geographic situation. For the simplification, we assume a grid-shaped network on a square-shaped uniform land with a side of \( \sqrt{A} \). Since the number of expressway corridors in a side is \( \frac{L}{2\sqrt{A}} \), the interval of the grid of the expressway network can be approximated as \( 2A/L \) as shown in Figure-1. The distance between points to another point will not be dependent of the density of the expressway network due to the assumption of grid-shaped road network. However, when the length of expressway increases as \( L + dL \), the distance of access and egress to the expressway network is reduced and replaced by the driving distance on the expressway. Since the access and egress distance is represented by the interval \( 2A/L \) of the expressway network, this replaced distance by \( dL \) becomes \( (2A/L^2)dL \). We are going to
evaluate the benefit $dB$ created by time reduction produced by this replaced distance. Transport demand of passengers and freights is here assumed to be proportional to the population $P$. The value of time in transport is assumed to be proportional to GDP per capita $I$, and we let $v_N$ and $v_E$ speed on ordinary road and expressway respectively. When $k_1$ is a constant, the benefit $dB$ will be as follows.

$$dB = k_1 \frac{PAI}{\Delta v L^2} dL \quad (1)$$

when, $\Delta v = \left( \frac{1}{v_N} - \frac{1}{v_E} \right)^{-1}$

$$\quad (2)$$

On the other hand, the increase in construction and management cost of expressway $dC$ caused by $dL$ is assumed to be proportional to the unit cost $c$ and $dL$. When $k_2$ is a constant, $dC$ becomes as follows.

$$dC = k_2 c dL \quad (3)$$

Under the optimal situation, $dB = dC$. Therefore, from (1) and (3) the optimal length of expressway $L^*$ will be calculated by the following expression.

$$L^* = k_3 \sqrt{\frac{PAI}{c \Delta v}} \quad (4)$$

If we neglect the difference of $c, I$ as well as $\Delta v$, $L^*$ will simply be proportional to the value of $\sqrt{PA}$, which is so-called “Land Characteristic Index” developed by Japanese Ministry of Construction in 1970s and used for judging necessary length of regional trunk road network.

### 2.2 Deriving Normalized Development Level

We are going to discuss the relationship of the optimal length $L^*$ and actual length $L$ of a country in a time cross section in comparison with other countries or other time cross sections.

Firstly, we define the ratio of these two as “Development Level of Expressway” $\alpha$ as follows.

$$\alpha \equiv \frac{L}{L^*} \quad (5)$$

When the situation of a country in a time cross section is taken as the referential situation with a suffix of 0, the relative level of the “Development Level of Expressway” $\alpha$ of another situation is evaluated as the ratio of $\alpha$ as follows.

$$r_\alpha \equiv \frac{\alpha}{\alpha_0} = \left( \frac{L}{L^*} \right) / \left( \frac{L_0}{L_0^*} \right) = \left( \frac{L}{L_0} \right) / \left( \frac{L^*}{L_0^*} \right) = r_E / r_L \quad (6)$$

when, $r_E \equiv L / L_0 \quad (7)$

$$r_L \equiv L^* / L_0^* = \sqrt{\frac{PAI}{c}} / \sqrt{\frac{P_0 A_0 I_0}{c_0}} \quad (8)$$

Here, $r_\alpha, r_E,$ and $r_L$ are named as “Normalized Development Level”(NDL), “Normalized Length”, and “Normalized Land Characteristic Index” respectively. We are going to use this Normalized Development Level $r_\alpha$ for comparison analysis. The expression (6) will become linear by taking logarithms. Therefore if horizontal and vertical axes denote $\ln r_L$ and $\ln r_E$ respectively, then $\ln r_\alpha$ is expressed by the vertical distance between a sample point and the
diagonal line with 45 degree drawn from the origin which denotes the referential point (cf. Figure-2). Any point on a 45 degree line on the plain has the same “Normalized Development Level (NDL)”. NDL indicates the relative expressway development level in comparison with the referential situation, which considers the geographical, economic and demographic situation, by referring a sample situation. Therefore, if NDL is larger than 1, it means the relative expressway development level of a sample is better than the referential situation.

2.3 Preparation of Calculation

2.3.1 Data on expressway’s length
Since the definition and the quality of expressway are not common and dependent on country, we use data which the International Road Federation collects and opens to the public. Travel speed on expressway $v_E$ and ordinary road $v_N$ are basically set to be 75km/h and 35km/h respectively considering data of Japanese Road Traffic Census (2005), and assumed to be common over countries for the simplification in this study. This strong assumption might be modified in the further study. Therefore, $\Delta v$ is calculated 65km/h by (2). GDP or GRP and population are collected Angus Maddison (1963-2008), Bureau of Economic Analysis (1981-2008), Chinese Statistic Yearbook (1990-2008), World Statistic Yearbook (1985-2005), etc.

2.3.2 Data on construction cost of expressway
Due to the limitation in availability of data, we estimate construction cost function from data of 24 countries (2000-2008). Sources of data are listed in the Appendix 2. Note that the construction cost of each country is an average of some projects in each country. We assume that the construction cost will be affected by geographical condition including a risk of earthquake, demographic condition including population density and several other factors. Various geographical and demographic variables are prepared to explain unit construction cost. The following is the result of regression analysis with comparatively high fitness to the unit construction cost of expressway $c$ (mil.USD/km).

$$c = 2.52 \times 10^9 \times 10^{-1} \times I^{0.7} \times Di^{0.35} \quad (R^2=0.63)$$

$t$-values

Here, $s$ denotes a dummy variable to show earthquake area or not: if a region is in earthquake area $s=1$, otherwise $s=0$. $I$ and $Di$ denote GDP per capita (USD) and population density in habitable area (persons/km$^2$). “Earthquake area” is defined as an area which experienced earthquake(s) of Richter’s Seismic Magnitude $M=5.0$ or more, and had one or more earthquakes in every five years during the recent 30 years, and judged using the database of US-Geological Survey. As the result, approximately 30% of sample countries are regarded “earthquake areas”. Figure-3 shows the fitness of the regression function of unit construction cost.
3. INTERNATIONAL COMPARISON OF EXPRESWAY DEVELOPMENT

3.1 Level of expressway development in 2005

Figure-4 plots sample countries with respect to logarithms of “Normalized Land Characteristic Index”: ln r_L in horizontal axis and “Normalized Length”: ln r_E in vertical axis by taking Japan (2005) as the reference. “Normalized Development Level”: r_\alpha can be read by dotted lines of 45 degree lines.

Among countries with large area or with large population which are plotted in the right hand, the Normalized Development Level (NDL) of US is almost same as Japan, and that of China is approximately 1/3 of Japan in 2005. Germany and France with lesser construction cost are also plotted in the right hand due to the low risk of earthquakes. NDL of France is almost same as Japan, while that of Germany is 1.4 times larger than Japan.

Among countries plotted in the left hand, Korea, Austria, Denmark show the equivalent NDL to Japan. Famous logistic-oriented country, the Nederland marks 1.8 times larger NDL than Japan. Japan 14000 in Figure-4 denotes Japan’s expressway development plan for the future with 14,000 km in length, the situation of which is almost equivalent to the current situation of the Nederland. China 2020 denotes also the development plan for the year 2020 with 100,000 km in length, the situation of which overtakes current situation of Canada.

Figure-5 shows those of member countries of EASTS which already has expressway network for reference. Three top class countries of Japan, Korea, and Taiwan are under almost same level of NDL followed by Malaysia. NDL of China is already significantly higher than Indonesia, Thailand, New Zealand, and the Philippines.
Figure 4 Comparison of Expressway Development in 2005 (Reference Point: Japan in 2005)

Figure 5 Comparison of Expressway Development in Asian Countries in 2005
3.2 Progress in NDL of sample countries

Figure-6 shows the chronological progress during 1985-2005 of NDL in sample countries. It is interesting that Japan, Korea and France experienced more or less same progressing tendency in NDL during the recent 20 years. US shows no progress in NDL in this period, while Germany, which is doubtlessly another leading country of expressway next to US, has been expanding its network up to now. China’s expressway has been expended tremendously, however, its NDL is still low due to its huge population and area.

3.3 Region-wise progress in NDL in Japan and China

Now, what will happen on the progress of NDL of each region in a country? This section focuses on eight regions of Japan who has paid significant attention on the “regionally balanced development” for the long period after WWII, and China who now focuses also to the “harmonized development” but still seems to have large regional disparity. In Japan’s case we consider the contribution of inter-regional traffic movement onto the transport volume in a region, since the size of a region in Japan is significantly smaller (cf. APPENDIX 1).

Figure-7 shows the progress of NDL of each region of Japan from 1965 to 2005. Expressway development was started in more or less central areas (Kanto, Kinki, and Chubu), then followed by their neighboring areas (Kyushu, Tohoku, and Chugoku) from 1980s up to early 1990s, and has almost caught up by remote areas (Shikoku and Hokkaido) in 2000s. For Hokkaido, the result under different \(v_N\) (45km/h) is also shown for reference, since the travel speed of ordinary road in Hokkaido is significantly high due to its specific geographical condition. Regional NDLs are already within the difference of 20%. Such “domestic saturation” in expressway network in Japan from 2000s might be one of the reasons of recent anti-expressway opinion in the public in Japan.
On the other hand in China in Figure-8, the regional difference is almost 5 times even after considering the regional difference in various factors. However, the recent value of NDL in eastern China, for example in Jiangsu province, significantly exceeds NDL of Japan. Feeling of upper-mentioned “saturation” in Japanese people will be affected when they are well informed these international situations of expressway development.
4. REGIONAL BALANCE IN EXPRESSWAY DEVELOPMENT

4.1 Deriving Regional Balance Index
As mentioned in Chapter 2, samples having the same value of NDL will be plotted along a 45 degree line on a ln r_L versus ln r_E plain such as Figure-2 and 3. This means that we can judge a sort of regional development policy of a country by analyzing the scattering tendency of sample points of regions plotted on the plain. If the slope is larger than 1, expressway development is excessively concentrated to more needed areas with priority. If the slope equals 1, it means that expressway is developed in equivalent to each region’s needs. If the slope is less than 1, the priority of expressway development is taken place in comparatively less needed areas (often rural and disadvantageous areas).

Therefore, when a is the slope calculated by regression analysis applied to sample regions of a country plotted on a ln r_L versus ln r_E plain, “Regional Balance Index”(RBI) is defined as follows.

\[
RBI \equiv a - 1
\]  

\begin{align*}
RBI > 0 & : \text{priority development to more needed areas} \\
RBI = 0 & : \text{balanced development} \\
RBI < 0 & : \text{priority development to less needed areas}
\end{align*}

4.2 Progress of Regional Balance Index in Japan, US, and EU
Figure-9 shows the plotting of Japan’s eight regions by ten years from 1985 to 2005. Regional Balance Index (RBI) has been significantly descending by year and it gets near to almost zero. Figure-10 shows the progress of RBI by year in Japan, US and EU. Each state in US, and each one of 12 early member countries is regarded as a “region”. We can see that Japan concentrated its expressway investment into more needed areas with much priority up to 1980s, and then gradually sifted its policy into more balanced development from 1990s up to now, and recently it almost reaches to the level of RBI of US as well as of EU. The low level of RBI in US might be attributed to its advanced development of its expressway system from early stage. Also low RBI in EU maybe reasoned by the fact that expressway development was promoted by each country for long years even under an umbrella of EU. We tried the same analysis for China, however, we could not get to a clearly consistent results like Figure-9. China’s development policy of expressway system should be further studied by considering other factors such as export-driven economy which has been playing a significant role in coastal areas.
Figure 9 Progress of Regional Balance Index (RBI) in Japan

Figure 10 Progress of Regional Balance Index in Japan, US and EU
5. CONCLUDING REMARKS

This study developed an international macroscopic comparison methodology of the level of expressway network development from the viewpoint of accessibility to the network; namely introduced an index of Normalized Development Level (NDL) based on a simple but clearly formulated economic and geographic theory, which can consider the economic, demographic, and geographic difference of countries and regions. Regional Balance Index (RBI) was also introduced in order to show the level of regional balance numerically in expressway development.

NDL was applied to the time-series data of various countries over the world including EASTS’ member states and regions, and the relative situation of countries in expressway development as well as their historical change was numerically evaluated and discussed. Region-wise discussion in a country was also tried for Japan for China after considering the influence of inter-regional transport. Furthermore, RBI was calculated in the time-series of Japan, US and EU, and it was found that RBI of Japan has been reduced dramatically during recent decades and now approaches to the level of US and EU.

This comparison approach based on a simplified theory can be widely applicable even for countries and regions with limited data-availability such as those in developing world. It seems practically useful for governments or international authorities such as World Bank or Asian Development Bank to evaluate current situations in different countries, different regions, and different time-cross-sections comparatively, to review history of development in a country or in a region, and to discuss desirable direction of long-term development policy of expressway network for the future.

Some of the most important improvable points of the further study are: to expand the methodology so that the enrichment of traffic capacity of expressway would also be considered into the theory, to consider the possible effect of the increase in mobility or transport demand caused by the enrichment of the network as well as by the increase in income, to try to release some of strict assumptions for simplification of this study, and to improve the precision of parts of this study such as in the cost function.

Lastly, however not least, the authors sincerely would like to bring the deepest appreciation to the well-known Japanese road historian, Dr. TAKEBE Ken-ichi for his constructive comments and kind suggestions provided in advance to the publication of this study.

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APPENDIX 1: Consideration of Inter-regional and Passing Transport Demand in Regional Traffic for Comparatively Smaller Regions

In order to estimate the contribution of the factors of GDP per capita, the density of expressway network, and the size of area to the countrywide transport demand, we analyze region-to-region transport demand in Japan as well as in US (of integrated data set of different time cross sections), assuming that OD transport volume \( T_{mn} \) from region \( m \) to region \( n \) follows the expression (A1) as a function of population \( P \) of each region and transport distance \( r_{mn} \), and that gross traffic volume in region \( i \) follows the expression (A2).

\[
T_{mn} = k\sqrt{P_m P_n} \exp(-ar_{mn}) \quad \text{(A1)}
\]
\[
T_i = \sum_m \sum_n T_{mn} = k\sum_m \sum_n \delta_{imn} P_m P_n \exp(-ar_{mn}) \quad \text{(A2)}
\]

Here, \( a \) and \( k \) are constants. \( \delta_{imn} \) denotes a dummy variable, which equals 1 when traffic from region \( m \) to region \( n \) passes region \( i \), otherwise equals zero. For intra-regional transport in a region \( i \), \( r_{ii} \) is assumed to be \( \frac{i A_i}{2} \). We analyzed inter-regional passenger OD demand in Japan (2007, source: National Inter-regional Passenger Flow Survey) in order to estimate the constant \( a \) in (A1). Appendix Figure-1 shows the relationship between Traffic Volume, \( T_{mn} \) per \( \sqrt{P_m P_n} \) and distance. The constant \( a \) which demonstrates the damping factor of distance was estimated \( 2.5 \times 10^{-3} \) (1/km).

Now, \( \beta_i \) is defined as follows:

\[
\beta_i = \frac{T_i}{T_{ii}} \quad \text{(A3)}
\]

By replacing population \( P \) in the expression (8) by \( P_j \cdot \beta_j \sqrt{N} \sum \beta_j \), (here, \( N \) denotes number of regions), inter-regional transport demand and passing transport demand are to be considered in addition to intra-regional demand without causing conflicts to the calculation cases without such consideration.
APPENDIX 2: Data source for the analysis of construction cost of expressway

<table>
<thead>
<tr>
<th>Sample Countries (year)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vietnam (2009)</td>
<td></td>
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</table>

Data source:
- Euroroads [http://web.comhem.se/michaelfalk/euroroads/index.htm](http://web.comhem.se/michaelfalk/euroroads/index.htm)
- NEXCO East Japan [http://www.e-nexco.co.jp/open_schedule/opened_area/](http://www.e-nexco.co.jp/open_schedule/opened_area/)