INTERNATIONAL COMPARISON OF DEVELOPMENT LEVEL OF NATIONWIDE TRANSPORT INFRASTRUCTURES BY CONSIDERING GEOGRAPHIC, DEMOGRAPHIC AND ECONOMIC DIFFERENCES OF COUNTRIES

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ABSTRACT

This paper develops a scientific methodology specified by Normalized Development Level (NDL) to compare the development level of accessibility of transport infrastructures including expressway, high-speed rail (HSR), airport and sea port in different countries with the consideration the geographic, demographic and economic differences in each country. The development levels of network accessibility in various countries are examined by applying the developed methodology with the comparison of Japan as a refereed country. In addition, Normalized Development Level (NDL) is also applied for the integrated comparison of multi-mode passenger transport including expressway, high-speed rail and airport. Furthermore, particularly for the sea port (limited to container port in this study), an index named Geo-economic Concentration Index (GECI) that considers the port size, geographic, economic factors is also presented for comparing the development level of container port system from the perspective of port concentration.

Keywords: International Comparison, Transport Infrastructures, Development level, Concentration level

1. BACKGROUND AND INTRODUCTION

“How long expressway network is required in this country?” “Is high speed railway network extension really necessary to this extent?” “What is the suitable number of airport or seaport?”

"Is the port system concentrated or de-concentration?" These macroscopic questions should be answered by national infrastructure development visions or similar plans, which are usually based on poly-dimensional factors such as political and historical backgrounds or some policy-targets. However, these macroscopic plans have always been the subject of political or sentimental criticism of both-sides; "already-too-much" side and "still-insufficient" side, since the basis of these plans are regrettably not persuasive enough.

One of the methodological approaches to these questions is Cost-Benefit Analysis which is often used in the economic evaluation of individual infrastructure investment projects. For example, Godinho (2012) addressed the optimal timing for building a road within a cost-benefit framework, and Olsson (2012) presented the cost-benefit methodology used in the appraisal of railway infrastructure in seven countries in Europe. However, Cost-Benefit Analysis has not yet been applied to such macroscopic problems such as nationwide expressway network planning or countrywide railway investment policy.

Another approach to such questions is showing the position of the relative position of development level of transport infrastructure of a nation through an adequate international comparison. It may be easy to be understood as far as suitably processed and presented since people are usually sensitively interested in concerned about the relative positioning of his/her country in comparison with other countries. However, scientific methodology for international comparison of development level of transport infrastructure could hardly be found in literature. As a matter of fact, simple comparison of absolute amount such as total length of network, density, total turnover, turnover per capita and so on, 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. The reason resulted in the contradiction of the above results is the differences among countries in geography, demography and economy. It is extremely important to suitably and theoretically consider the influences of these differences when we compare the development level of transport infrastructure scientifically.

Methodologies of comparing different things in other fields, such as "Similitude" in the field of mechanic engineering (for example, Raymond (1975)), and "Scaling" in zoology (for example, Schmidt-Nielsen (1975) and (1984)) provide reference to this study. Both of the methods build a model with a focus on hypothetic basic principles which assumes two different things are in common inherently, and properly abstract the differences between the two things such as size. This idea is basically adopted in this study.

The basic concept of the methodology is to develop a relative evaluation approach of the development level of transport infrastructure in a country by calculating the ratio of the realized amount (for example length of expressway network) to the theoretically optimum amount of transport infrastructure, and to compare the ratio internationally and chronologically by taking a certain country in a certain year (for example Japan 2005) as the reference point. The "theoretically optimum amount" is derived by the equilibrium state model of marginal increase of utility and cost brought by the marginal increase of transport infrastructure. Factors such as population and total or residential area of a country as well as GDP per capita which directly influences the value of time, geological condition (namely seismic factor) which influences the unit construction and maintenance cost are theoretically reflected from the viewpoint of network accessibility.

The methodology has been firstly tried in IEDA (2005) and in TAKEBE (2010a and 2010b) for international comparison of the level of development in expressway network, 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 IEDA and KONDO (2011) further generally the developed methodology by considering the geographic and geo-economic differences of countries.

This paper further extended the developed methodology to various nation-wide transport infrastructures: expressway network, airport, high-speed rail network, and sea port, as well as applied for integrated comparison of multi-mode passenger transport in various countries. Furthermore, particularly for sea port, an index for measuring the concentration level of port system is developed with the consideration of the geographic and economic factors among different countries.

2. BASIC THEORY FROM NETWORK ACCESSIBILITY VIEWPOINT

This section demonstrates the basic theory of evaluating the comparative level of transport infrastructure development from network accessibility viewpoint. The basic concept is to develop the "theoretically optimum amount" of infrastructure derived by the equilibrium state model of marginal increase of utility and cost, which is a trade-off of access time and construction cost. By comparing the ratio of the realized amount of infrastructure and the "theoretically optimum amount" by taking a certain country in a certain year, the development level can be compared internationally and chronologically. Next, we will show how the methodology is developed in four main transport infrastructures, namely expressway, high-speed rail, airport and sea port.

1) Model Formulation for Expressway and High-speed Rail (HSR) Network

Suppose expressway/HSR 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

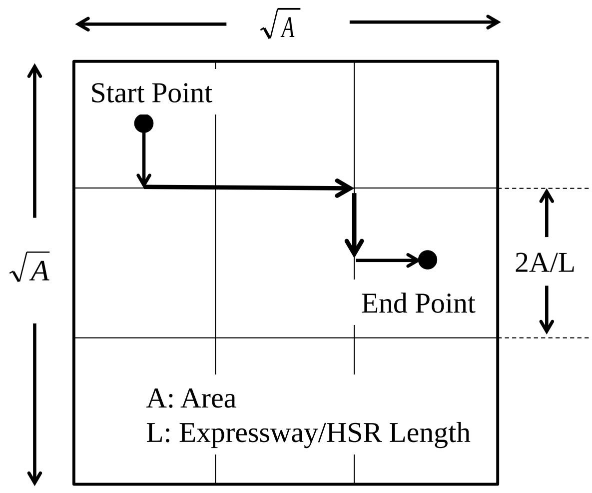

Figure 1 – Simplified land and expressway network

suitable level of expressway/HSR network being dependent on demographic, economic, and geographic situation.

For the simplification, we assume that: 1. Each country is in the shape of square; 2. The population of the country is evenly distributed; 3. Expressway/HSR is horizontally and vertically constructed in each country and uniformity distributed. The expressway/HSR network is assumed to be a grid-shaped network on a square-shaped uniform land with a side of $\sqrt{A}$. Since the number of expressway/HSR corridors in a side is L/2$\sqrt{A}$, the interval of the grid of the expressway/HSR network can be approximated as 2A/L as shown in Figure 1. Since the population is assumed to be average, the average access distance to Expressway/HSR network can be supposed to be proportional to 2A/L. Assume the average travel distance l of each country is the same and constant. Average Access Time to the network can be obtained from the average access distance and accessing speed to the network denoted as v_N, that is k(A/v_N), where k is a proportional coefficient; thus, Travel time in network is (l-K*A/L)1/V; As Total Time=Access time+ Travel time in network, then

$$\text{Total Time}=k\frac{A}{L}\frac{1}{v_N}+\left(l-k\frac{A}{L}\right)\frac{1}{V}=\frac{l}{V}+k\frac{A}{L}\left(\frac{1}{v_N}-\frac{1}{V}\right) \quad (1)$$

Assume that $\frac{1}{v_N}-\frac{1}{V}=\frac{1}{\Delta v}$, $\frac{1}{\Delta v}$ is a constant; Time value $w=k_w I$, where k_w is a constant; While Time cost(All population)=Total time × Time value × Population, then

$$TimeCost=k_a\frac{l}{V}PI+k_b\frac{A}{L\Delta v}PI \quad (2)$$

On the other hand, Construction Cost= Unit Cost × Length =cL, where c is unit construction cost(per km) of expressway/HSR; then, Total Cost equals to the sum of time cost of the whole population and construction cost, that is

$$TC=k_a\frac{l}{V}PI+k_b\frac{A}{L\Delta v}PI+cL \quad (3)$$

We use the Length of expressway/HSR as the determining factor to evaluate the development level of the network. Hereby, when

$$\frac{dTC}{dL}=k_b\frac{A}{\Delta v}PI\frac{\partial}{\partial L}\left(\frac{1}{L}\right)+c=0 \quad (4)$$

the total cost is minimized. Therefore, the optimal length of expressway/HSR L* can be calculated by the following expression.

$$L^*=k_3\sqrt{\frac{PAI}{c\Delta v}} \quad (5)$$

Then, 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" α as follows.

$$\alpha = L/L^* \tag{6}$$

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" α of another situation is evaluated as the ratio of α as follows.

$$r_1 \equiv \frac{\alpha}{\alpha_0} = (\frac{L}{L^*})/(\frac{L_0}{L^*{}_0}) = (\frac{L}{L_0})/(\frac{L^*}{L_0^*}) = r_E/r_L \tag{7}$$

$$\text{When, } \mathrm{r}_{E1} \equiv L/L_0 \tag{8}$$

$$r_{L1} \equiv L^*/L_0^* = \sqrt{\frac{PAI}{c}}/\sqrt{\frac{P_0 A_0 I_0}{c_0}} \tag{9}$$

In the above function, the only unknown part of the equation is the cost function. Next, we show how to determine the function of construction cost in expressway and HSR respectively.

Construction Cost Function of Expressway Network

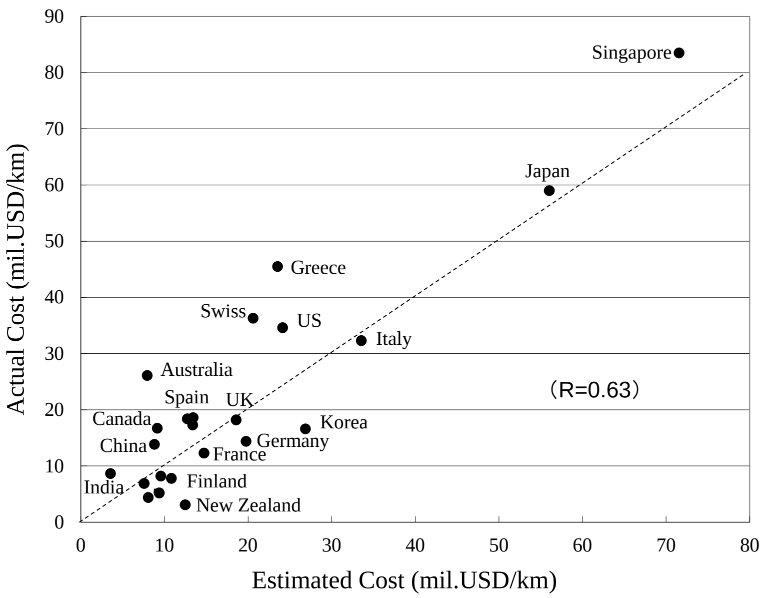

Figure 2 - Fitness of the regression function of unit construction cost

In order to determine the construction cost function, we use the actual data of construction cost in 24 countries (2000-2008). Note that the construction cost of each country is an average of some projects in each country. We assume that the construction cost is affected by geographical condition including the 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).

$$c = 2.52 \times 1.9^{s} \times I^{0.7} \times Di^{0.35} \quad (R^2=0.63) \qquad (10)$$
(2.6)(4.9)(3.9) (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/km2). "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-2 shows the fitness of the regression function of unit construction cost.

Construction Cost Function of High-speed Rail (HSR) Network

The unit construction cost of HSR is also calculated through SPSS regression. The data of 42 lines in 11 countries are collected and influential factors of unit cost are supposed as: Earthquake, Average residential area per capita, GDP (Gross Domestic Product) per capita, GDP per capita PPP (Purchasing Power Parity), GNI (Gross National Income) per capita, GDP per person employed, Population Density, Labour Force Rate, and Operation Speed. Regression model is picked as linear model y=ax1+bx2+c and nonlinear exponential model y=ax1bx2c. The final result is

$$c = k \times I^{0.797} \times V^{1.394} \times Pd^{1.161} \times AL^{0.277}, \; R^2 = 0.773 \qquad (11)$$
(2.5) (5.8) (6.8) (4.7) (t-vaule)

Where c: unit Cost(mil.USD/km); k: Constant; I: GDP per capita; V: Operation Speed; Pd: Population Density(Pd); AL: Average residential area.

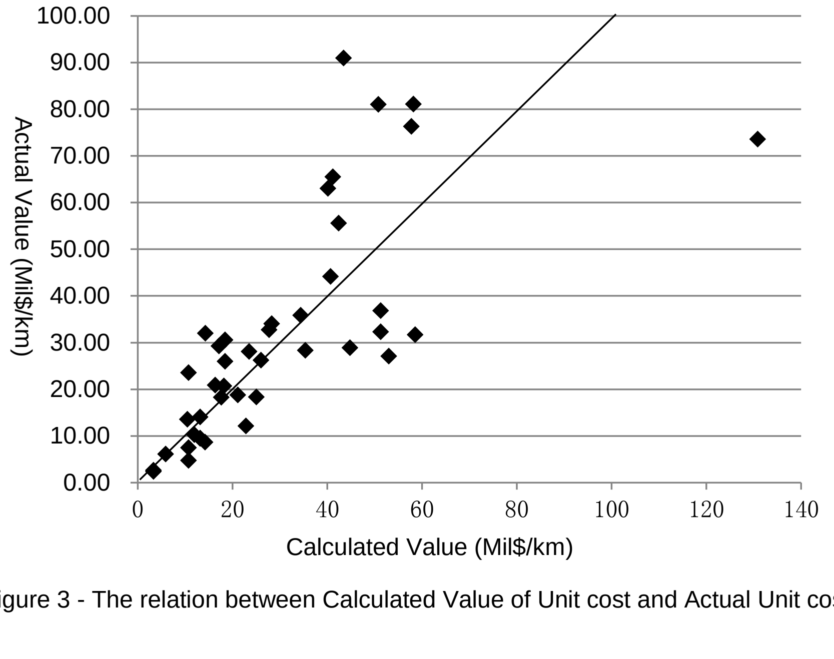

Figure 3 - The relation between Calculated Value of Unit cost and Actual Unit cost

For the purpose of simplifying the calculation, set $c = kc'V^d$. Same as expressway, the network length is considered as the determining factor to evaluate the development level. The optimal length of HSR is

$$L^{*} = k_{L} \frac{P^{\frac{1}{d+2}} A^{\frac{d+1}{d+2}} I^{\frac{1}{d+2}}}{c'^{\frac{1}{d+2}}} \tag{12}$$

According to the same theory above, Normalized Development Level of High-speed Rail is

$$r_2 \equiv \frac{\alpha}{\alpha_0} = (\frac{L}{L^*})/(\frac{L_0}{L^*{}_0}) = (\frac{L}{L_0})/(\frac{L^*}{L_0^*}) = r_E/r_L \tag{13}$$

$$\text{When, } r_{E2} \equiv L/L_0 \tag{14}$$

$$r_{L2} \equiv L^*/L_0^* = \frac{P^{0.295} A^{0.705} I^{0.295}}{c'^{0.295}} / \frac{P_0^{0.295} A_0^{0.705} I_0^{0.295}}{c_o'^{0.295}} \tag{15}$$

2) Model Formulation for Airport and Sea Port Systems

Different from expressway and HSR, for airport and sea port, the number of the port is used as the determining factor to evaluate the development level. As the airport is distributed on the land area, while sea port is distributed on the coastline, we introduce the methodology of airport and sea port separately.

Derivation of the Model for Airport Systemt

Same as expressway and HSR, suppose airport network of the number of airport n is constructed in a country with area A and population P. We assume that: 1. Each Country is in the shape of square; 2. Each airport's catchment area is a circle and defined as the area of πR_n^2 and the potential users are evenly distributed within the catchment area of each port. Then, the integral value of total travel distance inside one circle is

$$\int_0^R \frac{P}{A} 2\pi r dr \cdot r = 2\pi \frac{P}{A} \int_0^R r^2 dr = \frac{2\pi P}{3A} R^3 \tag{16}$$

$$\text{Where } R = \sqrt{A/n\pi}$$

For a country which has n airports, the whole country's air transport users' travel distance to the airport are D(n)

$$D(n) = \frac{2\pi P}{3A} R^3 n = \frac{2P}{3} \sqrt{\frac{A}{\pi n}} \tag{17}$$

While increase an airport the whole country's air transport users' travel distance to the airport will decrease: $dD(n)/dn = (-P/3) * \sqrt{A/\pi n^3}$. We assume people will use normal road to access and egress airport at a speed of v_N, the marginal time saving is $\frac{(-P/3)*\sqrt{A/\pi n^3}}{v_N} dn$. We convert the time saving into monetary form dB=$\frac{(-P/3)*\sqrt{A/\pi n^3}}{v_N} . Idn$. On the other hand, the marginal cost dC=Cdn, c is the unit cost per new airport. When dB=dC, the country's airport reach the optimal condition. The optimal number of airport n* is:

$$n^* = \sqrt[3]{\frac{I^2P^2A}{9v_Nc^2\pi}} \tag{18}$$

The unit cost of airport is estimated by the cost of runway which is derived via regression analysis by Daivd.C(2007) using 53 countries' data. The result is

$$\ln(c)=25.9-3.517\ln(I)+0.226(\ln(I))^2 \tag{19}$$

(4.66) (2.59) (2.76) (t-value)

According to the same theory above, Normalized Development Level Index of Airport is

$$r_3 \equiv \frac{\alpha}{\alpha_0} = (\frac{n}{n^*})/(\frac{n_0}{n^*_0}) = (\frac{n}{n_0})/(\frac{n^*}{n_0^*}) = r_E/r_L \tag{20}$$

When, $r_{E3} \equiv n/n_0$ (21)

$$r_{L3} \equiv n^*/n_0^* = \sqrt[3]{\frac{I^2P^2A}{9v_Nc^2\pi}}/\sqrt[3]{\frac{I_0^2P_0^2A_0}{9v_Nc_0^2\pi}} \tag{22}$$

Derivation of the Model for Sea port System

As there are various kinds of sea port, considering the data availability and importance of port to the national economy, only container port is considered in this study. Same as airport, in the case of sea port, the network accessibility is evaluated by the number of port. In the above functions to derive the theoretically optimum amount (optimal length for expressway and HSR, optimal number of airport), the trade-off between construction cost and access time is considered. However, in the case of container port, as number of port increases, though the access cost reduces, the port operation cost increases since economies of scale largely impacts the unit cost. Thus, the optimal number of ports is obtained by minimizing the access cost and terminal operation cost. Country's geographic shape and cargo transportation are simplified as shown in Figure 4.

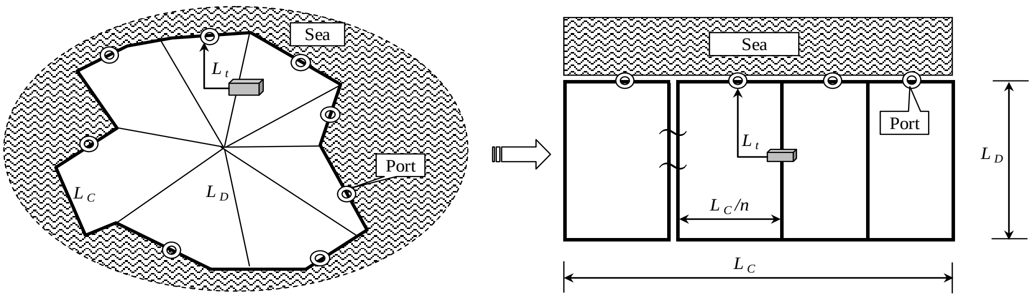

Figure 4 - A simplified model of cargo transportation

As shown in Figure 4, ports are assumed to be located along in line and access distance L_t is simplified as $L_t = L_D/n + L_c/2n$, where L_D, L_C and n are the average depth of the country from the coastline, the length of the coastline and the number of the container ports, respectively. If the access cost is proportional to the transportation distance L_t, the unit access cost C_t can be $C_t = \propto (L_D/n + L_c/2n)$, where a is a unit access cost coefficient. Moreover, the average unit terminal operation cost C_c is assumed to be an inverse proportional function of average trade volume T, $C_t = b \cdot (T/n)^{-\alpha}$, where α is the economies of scale in port operation and b is a constant. Then, the unit cost of a cargo C_u would be

$$C_u = C_t + C_c = a\left(\frac{L_D}{2} + \frac{L_C}{2n}\right) + b \cdot \left(\frac{T}{n}\right)^{-\alpha} \qquad (23)$$

Minimize C_u by $\partial C_u / \partial n = 0$, and the optimal number of ports n* is

$$\frac{n^*}{L_C} \propto \left(\frac{T}{L_C}\right)^{\beta} \qquad (24)$$

where the coefficient β is $\alpha/(1+\alpha)$. The regression analyses using the data of the actual number of ports, the length of coastal line, and international trade volume in 8 countries, namely: Japan, China, Korea, US, UK, France, Spain and Italy, in the years of 1977, 1984, 1994 and 2004, give a value of β equivalent to 0.5. According to the same theory above, Normalized Development Level Index of container port is

$$r_4 \equiv \frac{\alpha}{\alpha_0} = (\frac{n}{n^*})/(\frac{n_0}{n^*_0}) = (\frac{n}{n_0})/(\frac{n^*}{n^*_0}) = r_E/r_L \qquad (25)$$

$$\text{When } r_{E4} \equiv n/n_0 \qquad (26)$$

$$r_{L4} \equiv n^*/n_o^* = \sqrt{\frac{TL_C}{T_0 L_{C_0}}} \qquad (27)$$

3) Explanation on the application of the methodology

Above explains the basic theory to evaluate the development level of expressway, HSR, airport and container ports. Next, we demonstrate how to use this theory to compare the development level among countries. Here we names r, r_E, and r_L as "Normalized Development Level"(NDL), "Normalized Existing Level", and "Normalized Land Characteristic Index" respectively. This Normalized Development Level r is used for comparison analysis. The expression (7), (13), (20), (25) becomes linear by taking logarithms. Therefore if horizontal and vertical axes denote as $\ln r_L$ and $\ln r_E$ respectively, then lnr 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 as shown in Figure 5. 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 infrastructure development level of a sample is better than the referential situation.

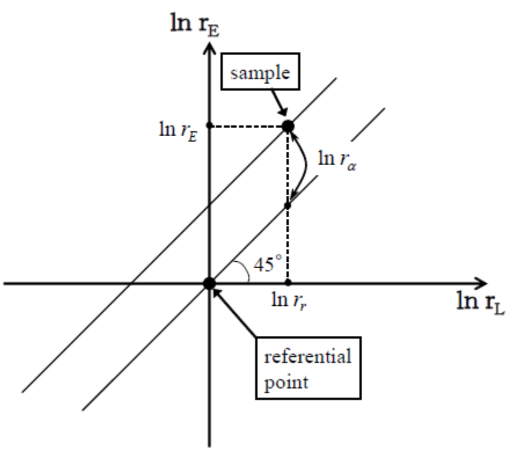

Figure 5 - rL, r_E and r

3. INTERNATIONAL COMPARISON OF NETWORK DEVELOPMENT FROM ACCESSIBILITY

In this section, the developed index is applied to the actual transport infrastructure networks in Asian, European countries as well as US. The application results of expressway, HSR, airport and container port are shown below respectively.

1) International Comparison of Expressway Network

Data on expressway 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 referring to data of Japanese Road Traffic Census (2005), and assumed to be common over countries for the simplification in this study.

Comparison of development level of expressway in 2005

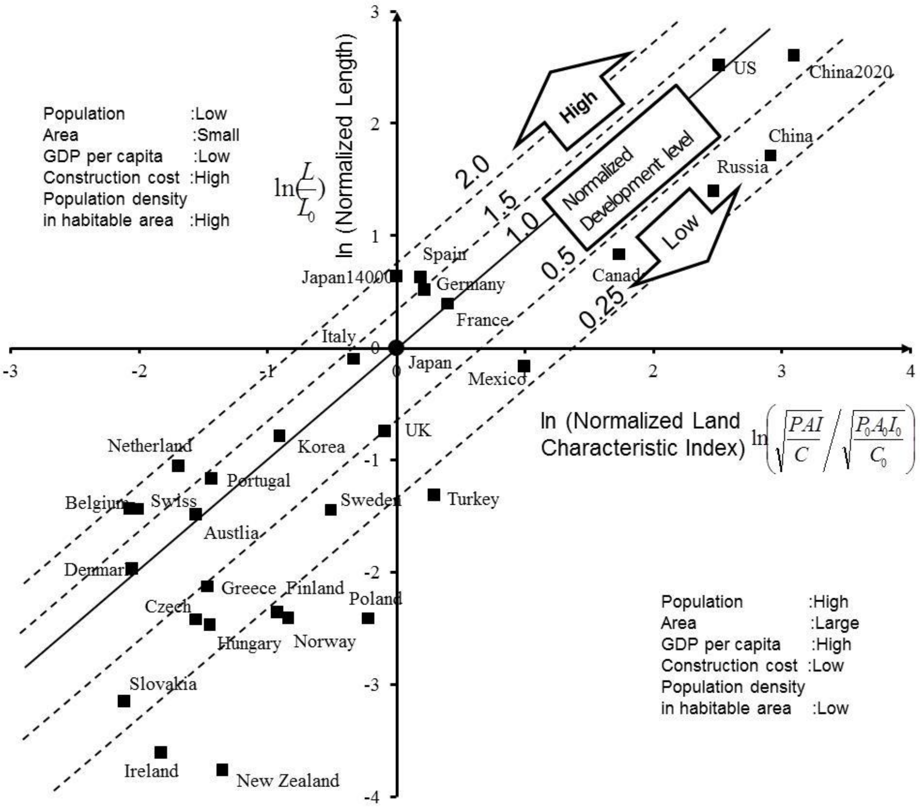

Figure 6 - Comparison of Expressway Development in 2005 (Reference Point: Japan in 2005)

Figure 6 plots sample countries with respect to logarithms of “Normalized Land Characteristic Index”: $\ln r_L$ in horizontal axis and “Normalized Existing Level”: $\ln r_E$ in vertical axis by taking Japan (2005) as the reference. “Normalized Development Level”: r 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 the 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 shows the equivalent NDL to Japan. Famous logistic-oriented country, the Nederland marks 1.8 times larger NDL than Japan. Japan 14000 in Figure-6 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.

2) International Comparison of HSR Network

Data on length of HSR

In order to obtain the comparable data, the definition of High-speed rail is necessary. In this study, the definition of UIC (International Union of Railways) is used, which is “High-speed rail is the systems of rolling stock and infrastructure which regularly operate at or above 250 km/h (155 mph) on new tracks, or 200 km/h (124 mph) on existing tracks.”

According to the data from UIC, 15 countries or areas which have High-speed rail in operation are selected, which are Belgium, France, Germany, Italy, Netherlands, Spain, Switzerland, United Kingdom, China, Taiwan, Japan, South Korea, Turkey, US and Russia. Due to the fact that High-speed rail in China and US are only centralized in East China and Northeastern US and these two countries are relatively large, besides China and US, East China and Northeastern US are specially considered as 2 areas in the comparison. (East China: the area of China except Inner Mongolian, Ningxia, Ganshu, Qinghai, Tibet and Xinjiang, which haven’t had High-speed rail in operation. Northeastern US: Maine, New Hampshire, Vermont, Massachusetts, Rhode island, New York, Connecticut, New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia.).

Comparison of development level of HSR in 2011

Based on above-mentioned coordinate axes, the result of international comparison of High-speed rail network length is shown in Figure 7.

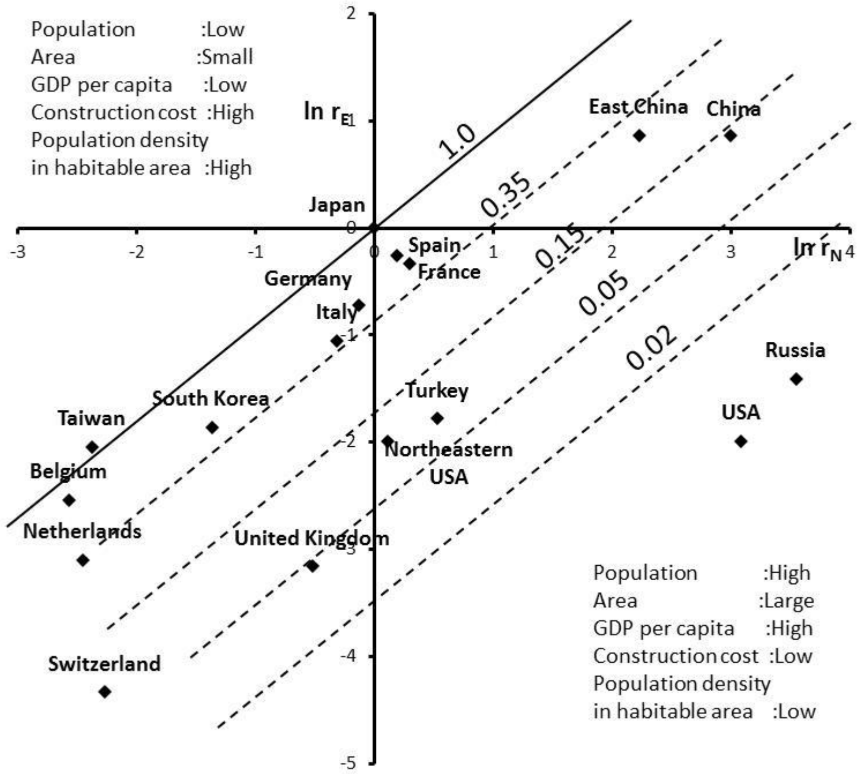

Figure 7 - Comparison of development level HSR in 2011 (Reference Point: Japan in 2011)

The result shows that only Taiwan and Belgium have higher development level than that of Japan (2011). All the countries can be divided into 3 groups. The 1st group (comparative development level≥1): Taiwan, Belgium and Japan. Although the existing level of HSR network in Taiwan and Belgium is not so high, the relatively small area and population results that it is relatively higher compare with the necessity level of those 2 areas. The 2nd group(comparative development level between 0.4 and 0.7): Spain, South Korea, Germany, Netherlands, France and Italy. France and Germany are known as the countries with advanced High-speed rail technology and well developed HSR network. However, in this comparison, the comparative development index of France and Germany are about half of Japan's level. The 3rd group (comparative development level under 0.3): East China, Switzerland, Northeastern US, China, Turkey, UK, Russia and US. Most of them are relatively large countries. Although China has the highest existing level of Length which is 2.36 times higher than Japan, the vast scale of population and area lead to a higher necessity level that exceeds the existing level, therefore the comparative development level is rather low.

3) International Comparison of Airport System

Data on the number of airport

In order to get comparable data set, the definition of airport is important. There are airport for public use, for defence use and for private use. In this study the definition of airport is the airport for public use where scheduled passenger flights exist.

Comparison of development level of Airport in 2005

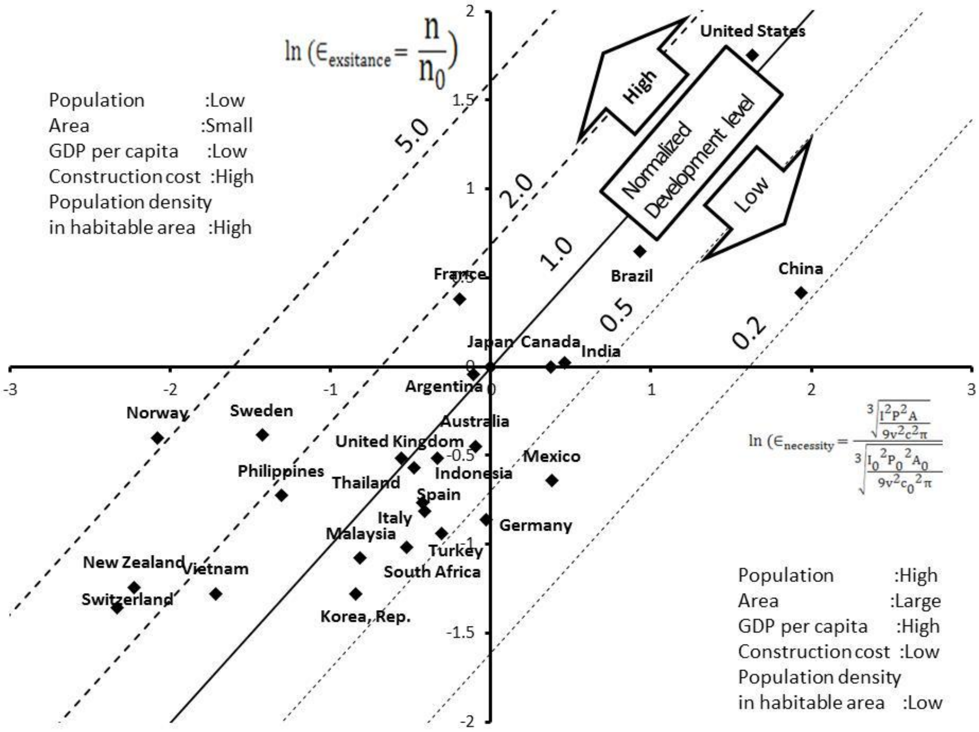

Figure 8 - Comparison of Development Level of Airport in 2005 (Reference Point: Japan in 2005)

From the results of NDL, many countries have less development level than Japan which below the 45-degree line across base point. Development level of United States and UK are slightly higher than that of Japan. In the developed country category, development level of France, Norway, Sweden, Switzerland are higher than that of Japan. In the developing country category, Vietnam and Philippines have higher development level than Japan. Relatively Lower GDP per capita in Vietnam and Philippines might account for the reason of this results, since the ratio of their GDP compare with Japan is smaller than the ratio of their airport supply compare with Japan.

4) International Comparison of Sea Port System

Data on the number of container port

Table 1-Data coverage in terms of throughput

	Australila	China	France	Italy	Japan	South Korea	Malaysis	Spain	United Kingdom	Unite States
number of ports	12	26	6	14	34	13	9	12	17	34
Throughtput of ports(a)	5,191	68,952	3,636	9,526	16,566	15,113	12,167	9,084	7,921	38,437
Total throughput(b)	5,191	75,640	4,001	9,857	16,777	15,216	12,198	9,171	8,250	38,498
Coverage of throughtput(a/b)	100%	91%	91%	97%	99%	99%	100%	99%	96%	100%

Note: Throughput unit: 1,000 20-ft equivalent units.

Same as airport, the accuracy of data of number of port is extremely important since it is directly affected on the results. We tried to cover all container ports in these countries, but due to lack of complete information, some minor ports were eliminated from counting in the number of port in some countries. In spite of this, the container throughput of the ports concerned account for a high percentage of the total throughput. As shown in Table 1, data coverage rate is at least 90% of the total throughput, indicating the result can represent the actual situation to a large extend.

Comparison of development level of container port in 2005

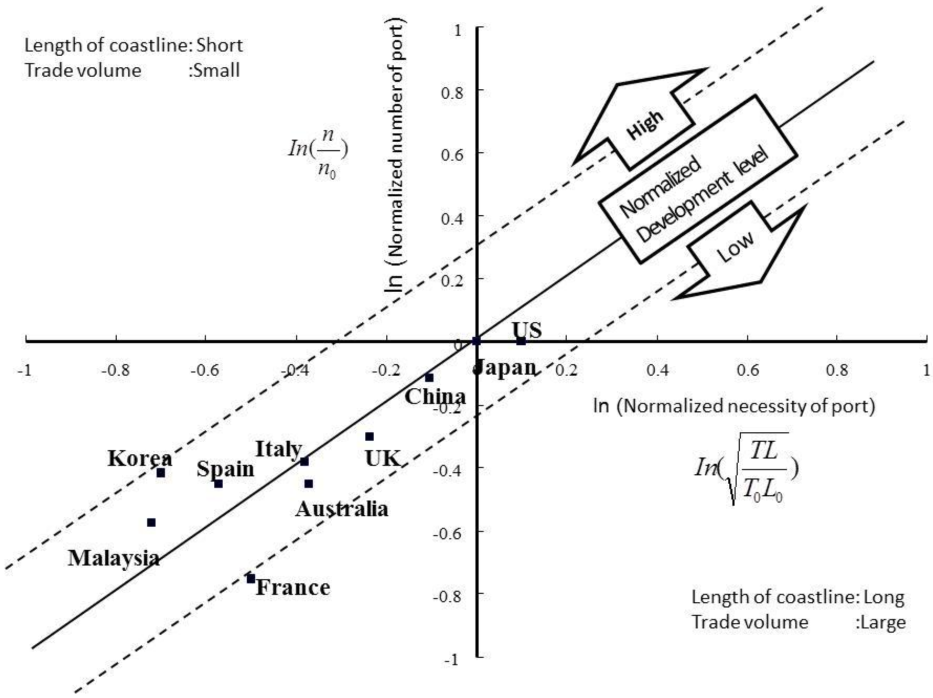

Figure 9 - Comparison of Development Level of Container Port in 2005 (Reference Point: Japan in 2005)

From the results showing in Figure 9, it can be seen that the development level of Korea, Malaysia and Spain is relatively in a high position. The common feature of these three countries is that their coastline is short and volume of international trade amount is quite low, so that there is no necessity to build a large number of ports. In fact, except US, all the other countries have smaller Land Characteristics Index than Japan, since Japan has very long coastline as an island country and large international trade volume. Italy and China are in the same level with Japan, while UK, Australia US and France are in a lower position than Japan. Since the data coverage of China and France is relatively low, their actual development level is supposed to be elevated a little if the complete data is available.

5) Integrated Comparison of Multi-mode Transport Infrastructures

Above analysis shows application results of NDL to four types of transport infrastructure, namely expressway, HSR, airport and container port respectively. In this part, an integrated comparison focusing on the passenger transportation including expressway, HSR and airport is introduced.

Since the developed index is based on the demand of all population in a country, in the case of multi-transport modes comparison, the demand of each transport mode should be allocated based on the respective mode share. Due to the data availability and data conformity, passenger movement (Passenger-km) mode share is chosen to represent the mode share. Besides, rail mode share is regarded as the demand factor of High-speed rail and road mode share is considered as demand factor of expressway. Suppose the mode share of each mode is a_{Exp}, a_{HSR} and a_{Air}, the Normalized Development Level equations of each mode changes to

Expressway:

$$r_{Exp} = \frac{\dfrac{L_i}{L_o}}{\sqrt{\dfrac{(a_{Expi}P_i)\ A_i I_i^{1.5}}{c_i}} \Bigg/ \sqrt{\dfrac{(a_{Exp0}P_o)\ A_o I_o^{1.5}}{c_o}}} \quad (28)$$

High-speed rail:

$$r_{HSR} = \frac{\dfrac{L_i}{L_0}}{\dfrac{(a_{HSRi}P_i)^{0.295} A_i^{0.705} I_i^{0.295}}{c_i'^{0.295}} \Bigg/ \dfrac{(a_{HSR0}P_0)^{0.295} A_0^{0.705} I_0^{0.295}}{c_o'^{0.295}}} \quad (29)$$

Airport

$$\gamma_{Air} = \frac{\dfrac{n_i}{n_0}}{\sqrt[3]{\dfrac{I_i^2(a_{Airi}P_i)^2 A_i}{c_i^2}} \Bigg/ \sqrt[3]{\dfrac{I_0^2(a_{Air0}P_0)^2 A_0}{c_0^2}}} \quad (30)$$

Where a_i: mode share of objective country; a_0: mode share of reference country (Japan).

The application result is shown is figure 10. According to the result, the development level of Expressway has the highest percentage in most countries which means expressway is the basic transport infrastructure in most countries. Belgium has the highest level in integrated comparison. The reason why Belgium has high level in all transport modes is that Belgium is located in the centre of France, Germany, Netherlands and UK. In order to connect these countries all transport modes should pass or transfer in Belgium, which leads to the high existing level of transport infrastructure. Moreover, Belgium is a relatively small country and has limited population, which means the necessity level of transport infrastructure is not so large. Considering the above reasons, it is not a surprising result that Belgium has quite high level of transport infrastructure among the countries concerned, indicating that the developed index is reliable in showing the comparative development level among countries. Furthermore, the results show that the development level of High-speed rail in Japan has the higher percentage among all the countries, which means Japan focus on the developing of High-speed rail more than other countries.

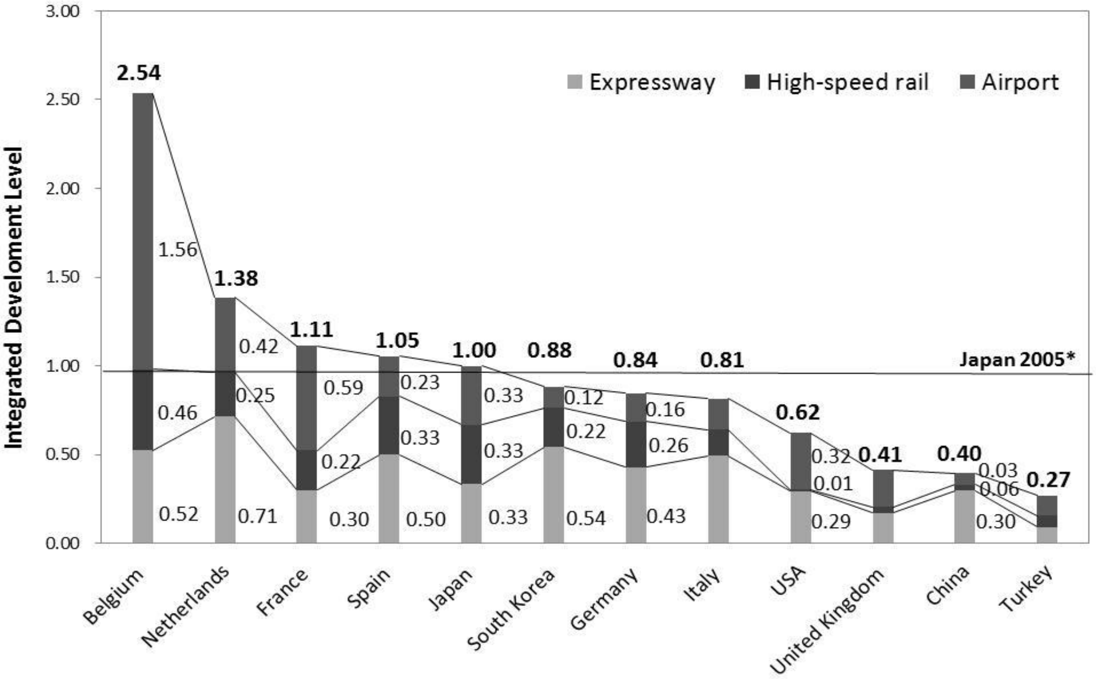

Figure10 - Results of integrated-transport mode comparison

*Japan 2005: For expressway and airport, the reference point is Japan in 2005, while for HSR, the reference point is Japan in 2011 since HSR is developed rapidly recently that requires the more undated data.

4. CONCENTRATION/DE-CONCENTRATION IN SEA PORT

Above analysis compared the development level of infrastructures among countries from the viewpoint of network accessibility. However, in the container port development, accessibility which is evaluated by the number of port does not adequately represent the development level of the network, since the scale of the port greatly impact on the network efficiency. This is because in container port industry, large-size vessels only call on a few large-scale ports for the reason of economies of scale, and transshipment may result in higher cost and time lost. On the one hand, to construct a large number of medium or small size port can increase the inland accessibility; on the other hand, to construct a limited number of large-sized port can reduce the operation cost and attracts large-size vessels. These indicate two kinds of development strategy of container port: Concentrated Development and De-concentration Development. In this section, in addition to network accessibility, we propose another index to compare the development level of container port infrastructure from a different viewpoint: the concentration level of port system. The index compares the concentration level of container port considering the port size (denoted by the share of the throughput), as well as the geographic and economic factors of the country.

1) Developing Concentration/de-concentration Index

An index named Geo-Economic Concentration Index (GECI) is developed to compare the concentration level of container ports among countries. This index is developed based on the Herfindahl-Hirschman Index (HHI), which is a commonly used concentration measure in industry. It is defined as the sum of the squared market share of firms in a market expressed as $HHI = \sum s_i^2$, where s_i is the market share of the *i*th firm.

As the share disparity increases, the system becomes more concentrated. The HHI is derived into an appropriate concentration measure based on a strict assumption that all firms are engaged in the full competition in the same market. However, in reality, when applying to port market, the competition levels among ports are highly depended on the spatial location of the ports. For example, the competition between two ports located close with each other is much higher than two located far. Moreover, the HHI value is not comparable among different markets as the competition level may differ from one type of market to another. For example, when we apply the HHI to port systems in different countries, the HHI value of a small country with very few ports is much likely to be higher than that of a large country with many ports. Therefore, the HHI is not suitable to be applied in the port market in different countries.

The concept of the GECI is to introduce a weigh function which is expressed by the distance between two ports to indicate the level of competition between them, interpreted as the degree of the overlapping hinterland of the two ports. Normalizing the distance between ports in different country by incorporating the individ
ual characteristics of each country, such as geographic scale and economical scale, the index can be standardized and comparable among different countries.

In details, assuming that each port forms a local market consisted of its dominated market and overlapped market with all the other ports, in the local market, all the ports are behaved in full competition. Following the same derivation of the HHI, the GECI can be defined as:

$$GECI = \sum \frac{s_i^2}{\sum w_{ij} s_j} \tag{32}$$

where s_i , s_j are the shares of the *i-th* and the *j-th* port respectively. w_{ij} is defined as the weight of port *j* for port *i*, which indicates the degree of sharing the same market of the two ports, and expressed as an exponential function of the distance between port *i* and port *j*:

$$w_{ij} = \exp\left(-k \cdot \frac{r_{ij}}{D_{norm}}\right) = \exp\left(-k' \cdot r_{ij}\right) \tag{33}$$

where $k' = k/D_{norm}$; k is a constant and D_{norm} is a distance normalization factor.
Since countries differ in geographical and economic scale, the degree of competition among ports with respect to the distance may also vary from country to country. It is assumed that each country has an economically reasonable interval of ports D_{norm} as a standard distance based on its own characteristics. Use D_{norm} as the normalization factor, the distance in different countries can be normalized.

According to the derivation of optimal number of port in the basic theory for network accessibility, D_{norm} can be described as:

$$D_{norm} = \frac{L_c}{n^*} \infty \left(\frac{L_c}{T}\right)^{1/2} \tag{34}$$

Therefore, the relationship *k'* of between a referenced country in a referenced year and any other country in any year (denoted by k_0' and k_1') can be derived as:

$$\frac{k_1'}{k_0'} = \left(\frac{T_1}{T_0}\frac{L_0}{L_1}\right)^{1/2} \tag{35}$$

By employing the above equation, we can obtain the value of *k'* for each country if the value of a reference country k_0' is available.

2) International Comparison in Port Development

The GECI is applied to port systems in 10 selected countries in Asia, EU and US. The data coverage of ports concerned is shown in Table 1 above. From the application results shown in Figure 11, we can observe a consistent tendency that all the port systems in different countries are moving towards concentration, or concentration after a temporary de-concentration. In particular, the concentration tendency is quite distinct since middle 1990s, which agrees with the changing environment in container shipping industry that the increasing ship size and reduction of port of call has facilitated to the concentration of container ports. Another interesting fact is that except Japan and the UK, concentration degrees of different countries are reaching to a somewhat same level. Whether this is an appropriate range of concentration degree needs further investigation in the future study.

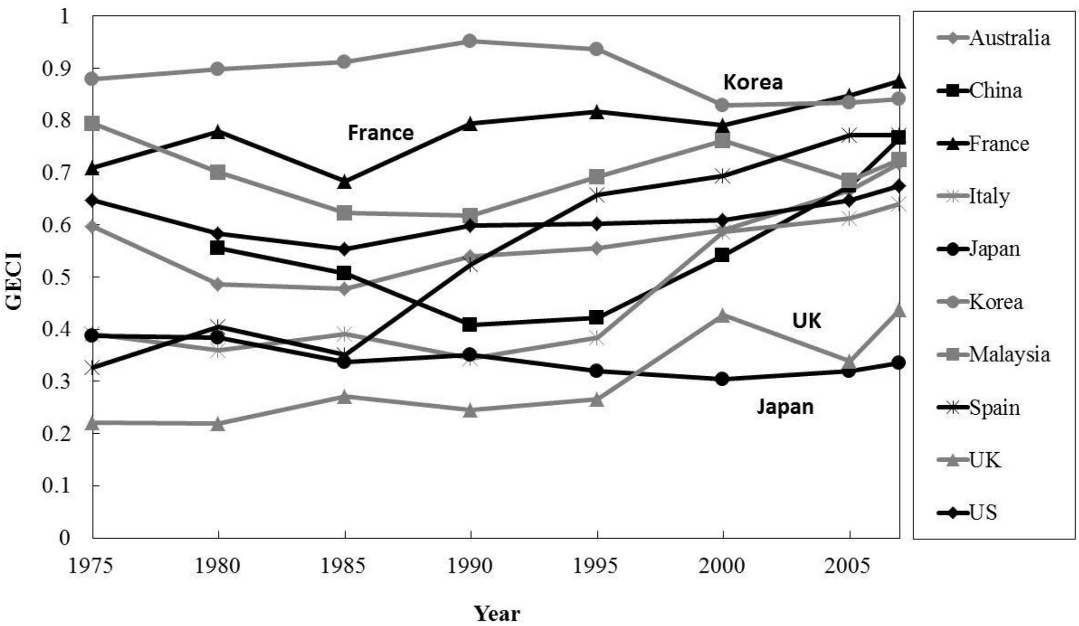

Figure 11 - International Comparison of the Level of Concentration of Container Port Systems by GECI

Comparing the results of GECI and NDL(Normalized Development Level, cf. Figure 9) in 2005, it can be noticed that Korea has both high level of concentration and accessibility, indicating that Korea has making efforts on not only the increase of the number of the port, but also the development of large size port in order to form a hierarchical port system. As for Japan, the level of accessibility level is in a relatively high position, but the level of concentration is at the bottom of all countries concerned, showing that Japan have focused more on constructing new ports rather than developing large size ports; while on the contrary, France has a low accessibility but high concentration degree, which indicates that France might have taken a concentrated development strategy that emphasize more on the development of a few selected ports.

5. CONCLUSIONS

This paper mainly develops an international macroscopic comparison methodology for evaluating development level of several transport infrastructures including expressway, High-speed Railway (HSR), airport and container port from the viewpoint of network accessibility. The index named Normalized Development Level (NDL) is developed based on a simple but clearly formulated economic and geographic theory, which considers the economic, demographic and geographic difference of countries and regions. In addition to Normalized Development Level (NDL), Geo-Economic Concentration Index (GECI), which evaluates the concentration level of container ports among different countries in a comparable way, is also introduced.

NDL is applied to expressway, HSR, airport and container port in various countries including Asian, European countries and US. The relatively development levels of the above transport infrastructures are evaluated by comparing with that of Japan as a referred country in a referred year. In addition, an integrated comparison considering the multi-mode of passenger transport including expressway, HSR and airport is also conducted, and the result finds out that Belgium has the highest level in integrated infrastructure development. Furthermore, GECI was applied to 10 selected container ports systems. In addition to the network accessibility, GECI considers the size of port and shows the development of port systems in the countries concerned from a different dimension: level of concentration.

One distinguished feature of this study is that the indexes proposed are developed based on a simplified theory that requires only macroscopic data for application, so that it can be widely applicable even for countries and regions with limited data-availability such as those in developing world. This methodology provides a simply but scientific tool for the governments and international agencies to understand the comparative international position of transport infrastructure development in different countries and regions, which seems to be practically useful as a reference for discussion on the desirable direction of long-term policy of transport infrastructure development for the future.

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