

The Methodology of International Comparison of High-speed Rail Development Level

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Investment in High-speed rail infrastructure is being supported by governments and supranational agencies with the declared aim of working for a more sustainable transport system. To the decision makers, the comparison of development level of High-speed rail among the world can provide several valuable information. This paper presents a model that can be used to compare the development level of High-speed rail through Length and Speed. The model in this study is based on the consideration of geography, economic, democracy and speed condition. By the worldwide High-speed rail data, the comparative development level and development trend of each country are expressed as the result.

Key Words : *High-speed rail, Development level, Comparative development index*

1. Introduction

As an efficient transportation mode, High-speed rail has been developed worldwide recently. On one hand High-speed rail partly reflects the transportation infrastructure development level of a country, on the other hand, construction of High-speed rail requires huge amount of investment. As a result, when government need to make the future plan about the High-speed rail, following questions are very important to the decision maker. Like “Is the new construction or expansion needed for my country? How much we need?”; “What’s the current development level of our country compare to other countries?”; “what’s the optimal development level of High-speed rail for your country?”

In order to answer these questions, a suitable methodology to evaluate the development level of High-speed rail which related to geography, demography and economy is essential for decision maker in government and railway company to understand current condition and make future plan.

There are two kinds of methodologies of evaluating the infrastructure development level: absolute evaluation and relative evaluation. One classical method of absolute evaluation is Cost-benefit analysis. However, Cost-benefit analysis is most used for microscopic planning and individual project, it also

needs huge and complex data to analyze. As a practical research, my study is trying development a method which can quickly and simply applied by other researchers. Besides, my study is dealing with the High-speed rail development level of a whole country, not an individual project, so that macroscopic thinking should be applied.

IGO(2010) has developed a scientific methodology which used normalized existing level and normalized necessity level for international comparison of the spatial accessibility of expressway with the consideration of size, population, economic development level of different countries¹⁾. Based on IGO’s research, Kondo(2011) considered the relationship between economy and traffic demand and add the capacity of expressway by the number of lane in his research²⁾. Their researches are one of the fundament of my research.

Chiu’s research (2011) has developed a methodology of macroscopic international comparison of the level of airport development with the consideration of the difference of countries of air transport characteristics and their social-economic, demographic, geographic condition. Two new indexes named Normalized Spatial Density Development Index and Normalized Recourse Quantity Development Index is derived in her research. Besides, the shape and size of the country are considered as the factors which can

affect the demand of long distance domestic travel and this research gives a method to derive the theoretic share of the long distance travel in one country³⁾.

By reviewing existing methodologies and researches, a comprehensive way of evaluating suitable development level of High-speed rail for a whole country hasn't been found. While finding absolute evaluation of High-speed rail is difficult, the comparison of High-speed rail among countries also can give decision maker very valuable information. Therefore, this study is to develop a model which can compare the development level of High-speed rail of each country. Generally speaking, the objective of this research is:

1. Developing a methodology which is suitable to compare the development level of High-speed rail of each country under the consideration of geography, demography and economy.
2. Applying the real data to derive the comparative development level and development trend of High-speed rail in each country.
3. Analyzing the characteristics and change of High-speed development in each country.

2. Methodology

(1). Basic theory

As a result of construction of High-speed rail network, the access distance and egress distance to the network will decrease, which means people's travel time can be reduced, in other words, the time cost of travelling will decrease. On the other hand, building High-speed rail needs vast of investment, so when total cost (time cost+construction cost) is minimal, the development level of High-speed rail is considered as optimal. In this research, development level of High-speed rail is reflected by Length of High-speed rail network and Speed of High-speed rail.

Basic assumptions of this methodology are:

1. Each country is in the shape of square;
2. The population of the country is averagely distributed;
3. High-speed rail is horizontally and vertically constructed in each country and High-speed rail network is average.

Suppose that:

A: Area of the country;

P: Population;

I: GDP per capita;

L: The length of High-speed rail network;

V: Speed of High-speed rail;

v_N : Accessing Speed(to High-speed rail network).

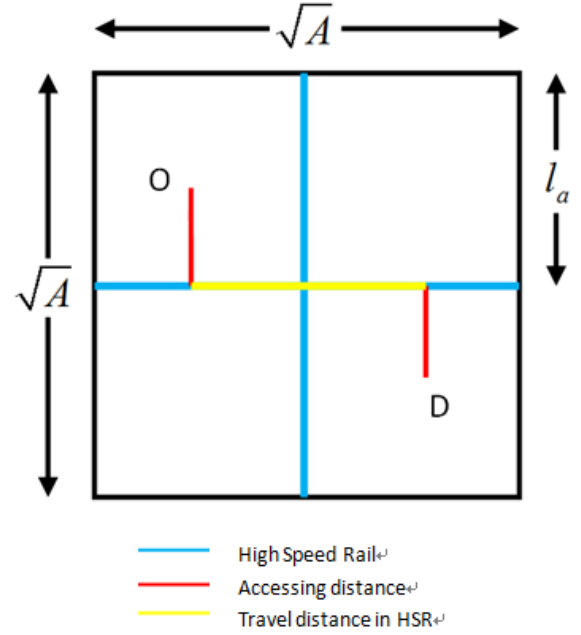


Fig.1 Simplification of country and High-speed rail network

Under the assumptive network of High-speed rail, the interval of High-speed rail network l_a can be calculated as

$$\frac{\sqrt{A}}{l_a} \times 2 \times \sqrt{A} \approx L \Rightarrow l_a = \frac{2A}{L} \quad (1)$$

Since the population is assumed as average, the average access distance to High-speed rail network can be supposed to be proportional to l_a . Assume the average travel distance l of each country is the same and it is a constant. Average Access Time to the network can be achieved from the average access

distance and v_N , it is $k \frac{A}{Lv_N}$, k is proportional coefficient;

Travel time in High-speed rail is $\left(l - k \frac{A}{L} \right) \frac{1}{V}$;

Total Time=Access time+ Travel time in High-speed rail

$$TC = k \frac{A}{L} \frac{1}{v_N} + \left(l - k \frac{A}{L} \right) \frac{1}{V} = \frac{l}{V} + k \frac{A}{L} \left(\frac{1}{v_N} - \frac{1}{V} \right) \quad (2)$$

Assume that $\frac{1}{v_N} - \frac{1}{V} = \frac{1}{\Delta v}$, $\frac{1}{\Delta v}$ is a constant;

Time value $w = k_w I$, k_w : constant;

Time cost(All population)=Total time×Time value×Population

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

Where k_a , k_b : constant; A: Area of the country; P: Population; I: GDP per capita; L: The length of

High-speed rail network; l : average travel distance; V : Speed of High-speed rail; vN : Accessing Speed(to High-speed rail network).

On the other hand, Construction Cost= Unit Cost $\times$ Length of High-speed rail= cL ;

c : Unit Cost(per km) of High-speed rail; L : Length of High-speed rail network.

Total Cost equals to the sum of time cost of all population and construction cost,

$$TC = k_a \frac{l}{V} PI + k_b \frac{A}{l \Delta v} PI + cL \quad (4)$$

In this research, Length of High-speed rail network and Speed of High-speed rail are selected as the comparative factors. Hereby, when

$$\begin{cases} \frac{\partial TC}{\partial L} = k_b \frac{A}{\Delta v} PI \frac{\partial}{\partial L} \left(\frac{1}{L} \right) + c = 0 & (5a) \\ \frac{\partial TC}{\partial V} = k_a PI \frac{d}{dV} \left(\frac{1}{V} \right) + L \frac{dc}{dV} = 0 & (5b) \end{cases}$$

total cost will be minimal.

(2). Unit Cost of High-speed rail

As the only unknown part of the equation, c (unit cost) need to be obtained. In the previous research of international comparison of expressway development level (Hitoshi IEDA, 2010), unit cost of expressway is estimated through regression analysis. In this research, unit cost of High-speed rail is calculated through SPSS regression. The data of 42 lines in 11 countries are collected and influential factors of unit cost are supposed as:

Geography: Earthquake, Average living area per capita. To the country with earthquake threat, infrastructure should be constructed with strong earthquake-proof level, which will largely influence the cost of construction. According to the previous research (IGO, 2010), the country with earthquake threat is identified as the country which had higher than magnitude 1v.5 earthquake in recent 30 years or had more than once periodical earthquake per 5 years. In this research, earthquake index is 1 as the country with earthquake threat and 0 as non-earthquake country. Living area is the area of a country which deducts the forest area. With the living area and population of one country, average living area per capita can be obtained. Less average living area can lead to higher construction cost of any infrastructure.

Economy: GDP per capita, GDP per capita PPP, GNI per capita, GDP per person employed. Since price index of each country is different and it has the

obvious effect to the construction cost, all the economic factors above are picked to reflect the price index of every country in this research.

Demography: Population Density, Labor Force Rate. Population density and labor force rate is separately related to the land price and the value of labor force, which make up of the important parts of construction cost.

Operation Speed. According to current technology, higher speed of High-speed rail need higher safety control and advanced technology, which lead to the increase of construction cost.

Regression model is picked as linear model $y=ax_1+bx_2+c$ and unlinear exponential model $y=ax_1bx_2c$. By means of SPSS, the result of linear regression and unlinear regression is shown as following :

Linear Function:

$$c=k+1.05I+0.095Pd+20.404EI, R^2 \text{ is } 0.738$$

Unlinear Function:

$$c=k \times I^{0.797} \times V^{1.394} \times Pd^{1.161} \times AL^{0.277}, R^2 \text{ is } 0.773.$$

c : unit Cost; k : Constant; I : GDP per capita; V : Operation Speed; Pd : Population Density(Pd); AL : Average living area; EI : Earthquake Index.

Since the linear function doesn't contain the operation speed and R^2 is smaller, unlinear function is chosen as the final function of Unit Cost.

$$c=k \times I^{0.797} \times V^{1.394} \times Pd^{1.161} \times AL^{0.277}$$

(3). Deriving Comparative development level index

For the purpose of easy calculation, set $C = kC'V^d$, therefore,

$$\begin{cases} \frac{\partial TC}{\partial L} = k_b \frac{A}{\Delta v} PI \frac{\partial}{\partial L} \left(\frac{1}{L} \right) + c = k_{b1} \frac{API}{L^2} + k_{b2} c' V^d = 0 & (6a) \\ \frac{\partial TC}{\partial V} = k_a l PI \frac{d}{dV} \left(\frac{1}{V} \right) + L \frac{dc}{dV} = k_{a1} \frac{PI}{V^2} + k_{a2} c' L V^{d-1} = 0 & (6b) \end{cases}$$

Where k_a, k_b are constants.

Therefore,

$$L^* = k_L \frac{P^{\frac{1}{d+2}} A^{\frac{d+1}{d+2}} I^{\frac{1}{d+2}}}{c'^{\frac{1}{d+2}}} \quad (7a)$$

$$V^* = k_V \frac{P^{\frac{1}{d+2}} I^{\frac{1}{d+2}}}{A^{\frac{1}{d+2}} c'^{\frac{1}{d+2}}} \quad (7b)$$

Where L^*, V^* are Optimal value of L, V .

Set actual length and speed of High-speed rail of a country as L and V ; Define the ratio of L, V and L^*, V^* as development level index of High-speed rail of Length and Speed α_L, α_V

$$\alpha_L = \frac{L}{L^*} = \frac{L}{k_L \frac{P^{\frac{1}{d+2}} A^{\frac{d+1}{d+2}} I^{\frac{1}{d+2}}}{c^{\frac{1}{d+2}}}} \quad (8a)$$

$$\alpha_V = \frac{V}{V^*} = \frac{V}{k_V \frac{P^{\frac{1}{d+2}} I^{\frac{1}{d+2}}}{A^{\frac{d+1}{d+2}} c^{\frac{1}{d+2}}}} \quad (8b)$$

Where k_L, k_V are the same constant among each country.

The development level of country i is α_{Li}, α_{Vi} ; Set the development level of Japan(2011) as the reference standard α_{L0}, α_{V0} , use $\frac{\alpha_{Li}}{\alpha_{L0}}, \frac{\alpha_{Vi}}{\alpha_{V0}}$ as the comparative development level index of country i

$$\frac{\alpha_{Li}}{\alpha_{L0}} = \frac{\frac{L_i}{L_i^*}}{\frac{L_0}{L_0^*}} = \frac{L_i}{L_0} \frac{L_0^*}{L_i^*} \quad (9a)$$

$$\frac{\alpha_{Vi}}{\alpha_{V0}} = \frac{\frac{V_i}{V_i^*}}{\frac{V_0}{V_0^*}} = \frac{V_i}{V_0} \frac{V_0^*}{V_i^*} \quad (9b)$$

Define r_{EL}, r_{EV} as comparative existing level index; r_{NL}, r_{NV} as comparative necessity level index; r_L, r_V as comparative development level index. The relationship among above index is

$$r_L = \frac{\alpha_{Li}}{\alpha_{L0}} = \frac{r_{EL}}{r_{NL}}, r_{EL} = \frac{L_i}{L_0}, r_{NL} = \frac{L_i^*}{L_0^*} \quad (10a)$$

$$r_V = \frac{\alpha_{Vi}}{\alpha_{V0}} = \frac{r_{EV}}{r_{NV}}, r_{EV} = \frac{V_i}{V_0}, r_{NV} = \frac{V_i^*}{V_0^*} \quad (10b)$$

According to the equation of unit cost, substitute d for 1.394

$$L^* = k_L \frac{P^{0.295} A^{0.705} I^{0.295}}{c^{0.295}} \quad (11a)$$

$$V^* = k_V \frac{P^{0.295} I^{0.295}}{A^{0.295} c^{0.295}} \quad (11b)$$

Therefore

$$\alpha_L = \frac{L}{L^*} = \frac{L}{k_L \frac{P^{0.295} A^{0.705} I^{0.295}}{c^{0.295}}} \quad (12a)$$

$$\alpha_V = \frac{V}{V^*} = \frac{V}{k_V \frac{P^{0.295} I^{0.295}}{A^{0.295} c^{0.295}}} \quad (12b)$$

Where k_L, k_V are the same constant among each country.

Comparative Development Level r_L, r_V are

$$r_L = \frac{\alpha_{Li}}{\alpha_{L0}} = \frac{r_{EL}}{r_{NL}} = \frac{\frac{L_i}{L_0}}{\frac{\frac{P_i^{0.295} A_i^{0.705} I_i^{0.295}}{c_i^{0.295}}}{\frac{P_0^{0.295} A_0^{0.705} I_0^{0.295}}{c_0^{0.295}}}} \quad (13a)$$

$$r_V = \frac{\alpha_{Vi}}{\alpha_{V0}} = \frac{r_{EV}}{r_{NV}} = \frac{\frac{V_i}{V_0}}{\frac{\frac{P_i^{0.295} I_i^{0.295}}{A_i^{0.295} c_i^{0.295}}}{\frac{P_0^{0.295} I_0^{0.295}}{A_0^{0.295} c_0^{0.295}}}} \quad (13b)$$

r_L, r_V is the indexes which reflect the development level of High-speed rail in a relative method. By taking natural logarithms, the function of r turns into linear function $\ln r = \ln r_E - \ln r_N$. Set up a coordinate axes as following, in which horizontal axes expresses natural logarithm of comparative necessity level and vertical axes expresses natural logarithm of comparative existing level.

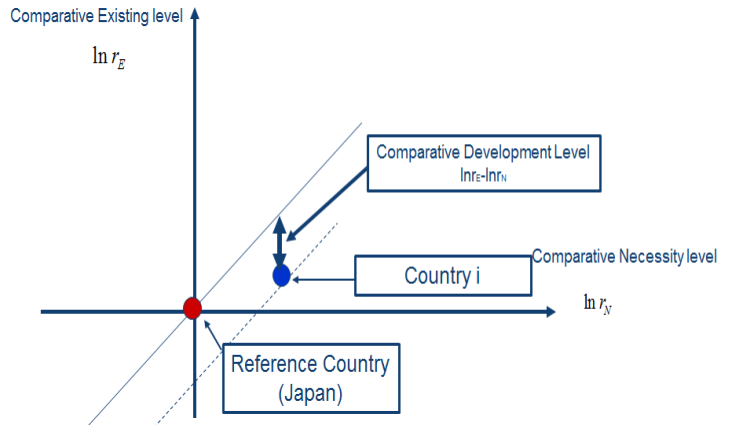


Fig.2 Coordinate axes of comparative development level

From the figure, it is easy to get the conclusion that $\ln r$ can be represented by the vertical distance between target country and diagonal through standard country. As a result, 2 countries which have the same comparative development level will be in the same 45 degree line. Besides, the country with high necessity level is in the right part and the country with high exiting level is located in upper position. This normalized approach enables to provide relative information of each country in the comparison.

3. Result and Discussion

In order to receive the comparable data, the definition of High-speed rail is necessary. Currently, there are numbers of definition about High-speed rail among EU, Japan, China, USA and other countries. As a result of international comparison, the definition of UIC(International Union of Railways) is chosen in this research, 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 UIC⁴⁾ and Wikipedia, 15 countries or areas which have High-speed rail in operation are picked this time, which are Belgium, France, Germany, Italy, Netherlands, Spain, Switzerland, United Kingdom, China, Taiwan, Japan, South Korea, Turkey, USA and Russia. Due to the

centralized in East China and Northeastern USA and these two countries are relatively large, therefore East China and Northeastern USA are also considered as 2 areas in the comparison. (East China: In this research, East China is the area of China except Inner Mongolian, Ningxia, Gansu, Qinghai, Tibet and Xinjiang, which haven't had High-speed rail in operation. Northeastern USA: Maine, New Hampshire, Vermont, Massachusetts, Rhode island, New York, Connecticut, New Jersey, Pennsylvania, Delaware, Maryland, District of Columbia.)

The Basic information of High-speed rail by country is collected through UIC report “High Speed Lines in the world, Updated 1st November 2011” and Wikipedia, the information is shown in table in Appendix.

The data of Area, population, GDP per capita, Average living space per capita are based on the “World Bank Database”⁵⁾.

Based on above-mentioned coordinate axes, the

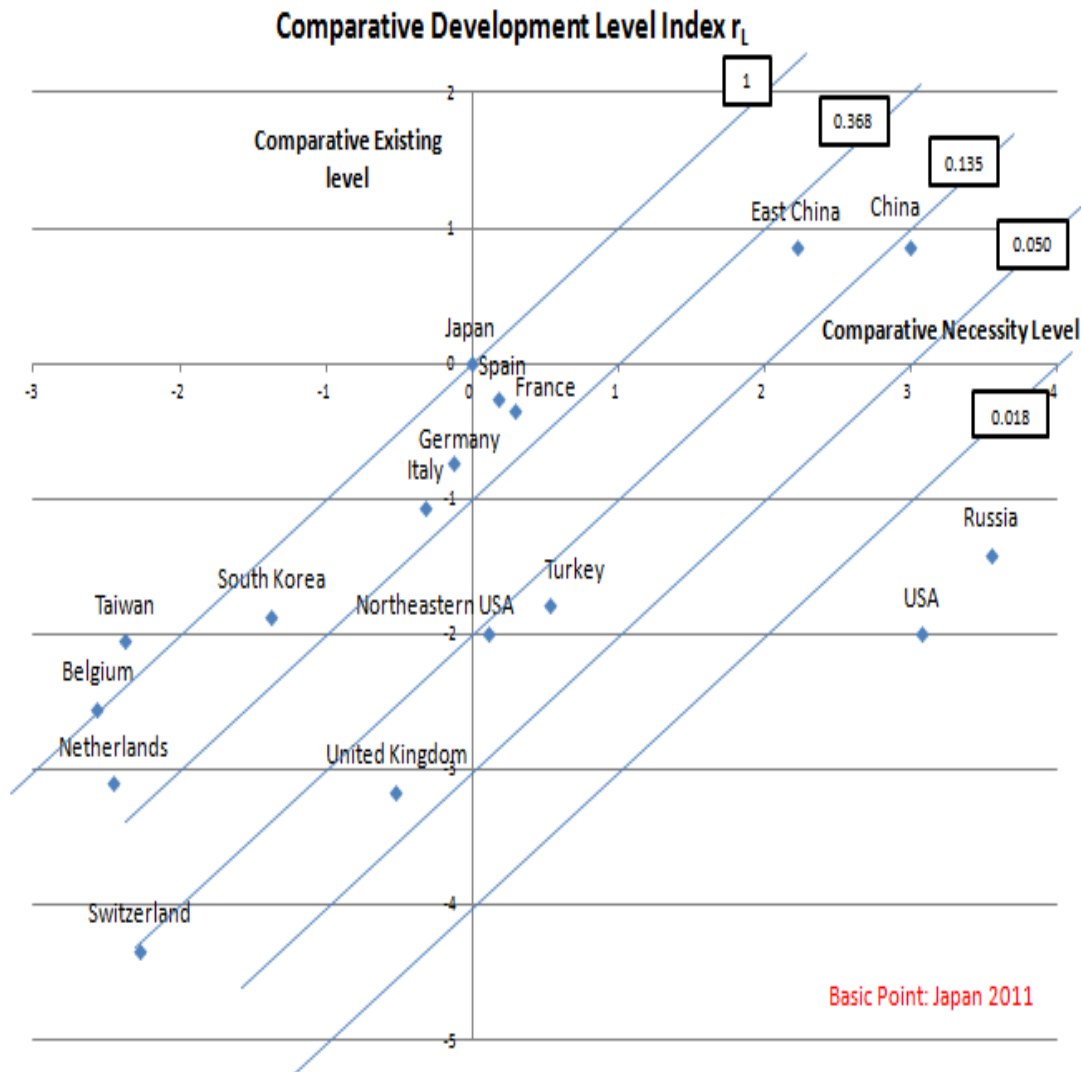


Fig3. Comparison of comparative length development level of 2011

fact that High-speed rail in China and USA are only result of international comparison of High-speed rail

network length can be represented in fig.3. The number in the box means the comparative development index number of the 45 °line.

According to the result of network length, only Taiwan and Belgium have higher development level than Japan(2011). All the countries can be divided into 3 groups. The first group(comparative development level ≥ 1): Taiwan, Belgium and Japan. Although the existing level of Taiwan and Belgium is not so high, the relatively small area and population cause it is relatively higher compare with the necessity level of those 2 areas. The second 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. However, in this comparison, the comparative development index of France and Germany are about half of Japan's level. The third group(comparative development level under 0.3): East China, Switzerland, Northeastern USA, China, Turkey, UK, Russia and USA, 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 the necessity level are much bigger than existing level, so that the comparative development is rather low. The gap between top (Taiwan) and bottom (USA) is about 233 times.

By applying time series data of all the countries in to the comparison, we can achieve the tendency of comparative development index r_L (Fig.5 in the Appendix)

Based on the tendency, Japan had the highest level of length until Taiwan completed their High-speed rail(Taipei – Kaohsiung) in 2007. Belgium became the top level of Europe since the L2 High-speed rail line(Leuven – Liège) was accomplished in 2002. Japan and most European countries developed their High-speed rail before 2000; on the other hand, all the countries in 3rd groups developed their High-speed rail system after 21st century.

The result of Speed is shown in fig.4.

From the result of speed, Comparative development level of Japan is lowest, China's level is highest among these countries, and France has the highest existing level of Speed. Basically because compare to other countries, the average Speed of High-speed rail in Japan 2011(257km/h) is quite slow, which means exiting level of Japan is low; in addition, the population density and GDP per capita of Japan are lo-

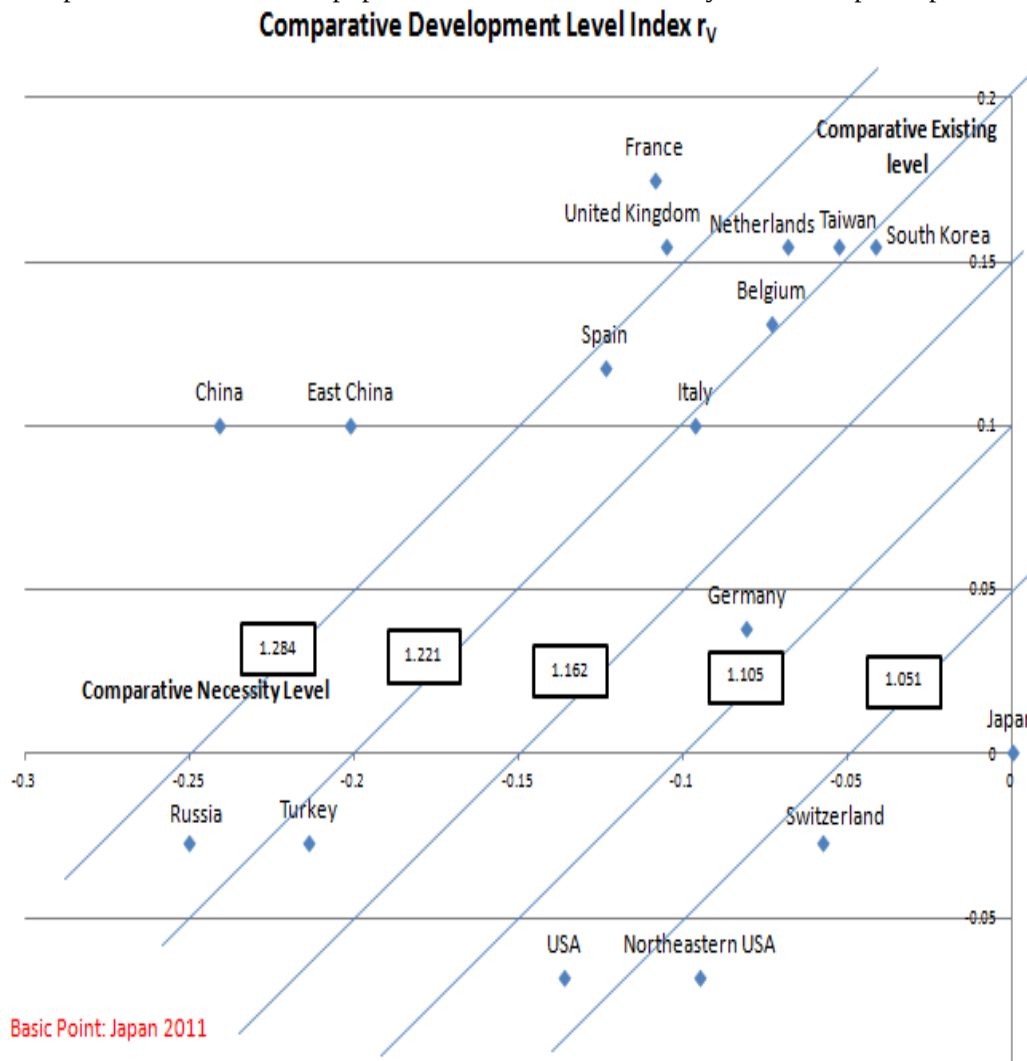


Fig4. Comparison of comparative speed development level of 2011

cated in high level which means necessity level of Japan is considerably high. Take those factors into consideration, the comparative development level of Speed in Japan is lowest. Being different from Length, the relatively big countries have lower necessity level of Speed than other countries, which means that network length is efficient to reduce travel time to big country but speed is crucial to small country. The Gap between top(China) and bottom(Japan) is 1.4 times which means the difference of Speed development level is relatively small.

Also, through time series data of all the countries in to the comparison, we can achieve the development tendency of Comparative Development Level r_v . (Fig.6 in the Appendix)

From the tendency of Comparative Development Level r_v , we can achieve the conclusion that to most areas except China, East China, Spain and Italy, the basic tendency of development level of speed is going down during 30 years in respect that the development of speed can't keep up with the growth of necessity which caused by the growing GDP per capita and population. China's level had a big jump in 2009 because the current longest High-speed line(Wuhan – Guangzhou 968km) opened with the operation speed in 300km/h, which is relatively higher than the 200km/h lines.

4. Conclusion

(1). This research developed a comparative model of international High-speed rail development level through the consideration of diverse geography, demography and economic condition. Function of unit construction cost is derived by SPSS regression. Length of High-speed rail network and Speed of High-speed rail are considered as the comparative factors in this model.

(2). Worldwide High-speed rail data are gathered, the output of the model expressed the High-speed rail comparative development position of each country through a 2-dimension figure. By applying the time series data, the development trend of High-speed rail in all countries is also achieved. The comparative development level of length and speed can be clearly understood and analyzed via these output.

(3). Based on the result of network length, all the countries can be divided into 3 groups. The first group(comparative development level ≥ 1): Taiwan, Belgium and Japan. The second group(comparative development level between 0.4 and 0.7): Spain, South Korea, Germany, Netherlands, France and Italy. The third group(comparative development level under 0.3): East China, Switzerland, North-eastern USA, China, Turkey, UK, Russia and USA.

The gap between top (Taiwan) and bottom (USA) is about 233 times. While through the result of speed, Comparative development level of Japan is lowest, China's level is highest among these countries. The relatively big countries have lower necessity level of Speed than other countries. The Gap between top(China) and bottom(Japan) is 1.4 times which means the difference of Speed development level is relatively small.

(4). According to the tendency of comparative development level index of length, Japan had the highest level of length until Taiwan completed their High-speed rail in 2007. Belgium became the top level of Europe since the L2 High-speed rail line was accomplished in 2002. All the countries in 3rd groups developed their High-speed rail system after 21st century. To most areas except China, East China, Spain and Italy, the basic tendency of development level of speed is going down during 30 years.

APPENDIX

Table Condition of High-speed rail by country(2011)⁴⁾

Country	High speed line in operation (Km)	Average speed in operation (Km/h)
Belgium	209	293
France	1896	306
Germany	1285	267
Italy	923	284
Netherlands	120	300
Spain	2056	289
Switzerland	35	250
United Kingdom	113	300
China	6299	284
Taiwan	345	300
Japan	2664	257
South Korea	412	300
Turkey	447	250
USA	362	240
Russia	650	250

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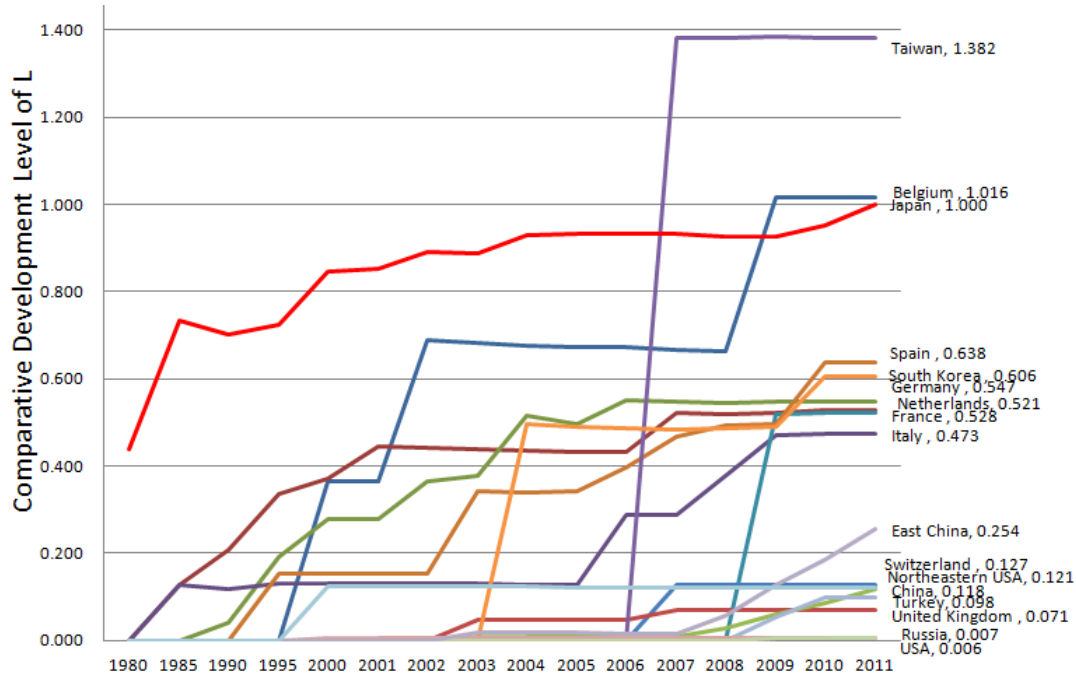


Fig.5 Trend of Comparative Development Level r_L

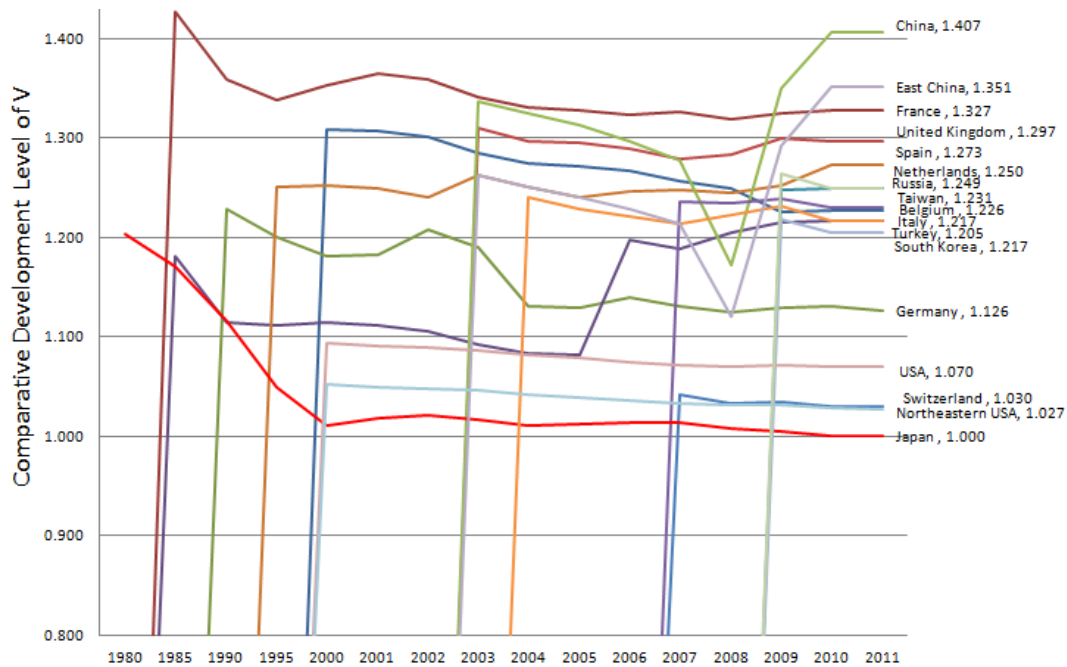


Fig.5 Trend of Comparative Development Level r_L