International Comparison of Transport Infrastructure Development Level by Considering Geographic, Demographic and Economic Difference of Countries

高速交通インフラ整備水準の国際比較手法

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掲　序

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August 10th, 2012

Abstract

Investment in High-speed transport infrastructure(High-speed rail, airport, Expressway…) is being supported by governments and supranational agencies with the declared aim of working for a more sustainable transport system. In order to make the future plan of High-speed transport infrastructure, a suitable methodology to evaluate the development level of High-speed transport infrastructure is essential. To the decision makers, while finding absolute evaluation of High-speed transport infrastructure is difficult, the comparison of development level of High-speed transport infrastructure among the world also can provide valuable information. Previous researches have studied the comparative model of expressway and airport, so firstly, this paper presents a model that can be used to compare the development level of High-speed rail. The model in this study is based on the consideration of geography, economic, democracy and speed condition. Basic theory is when total cost (time cost+construction cost) is minimal, the development level of High-speed rail is considered as optimal. The ratio of existing development level and optimal level is used as the development index. Comparative development level index of network length and operation speed are derived to evaluate the development level of High-speed rail in every country. By the worldwide High-speed rail data, the comparative development level and development trend of each country are expressed as the result. Japan’s regional data are also applied in the model and the regional development level index tendency is derived and analyzed. Due to the limitation of High-speed rail user, time cost of High-speed rail passenger is considered. Finally, the combination of other transport mode is considered by applying the passenger movement mode share as the factor of traffic demand. The normalized development level index of each mode is expressed by 3-dimentional figure. The detail of each surface is analyzed. Besides, the two kinds of model which can compare the development level of land transport with air transport are constructed.

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Chapter 1. Introduction

1.1 Background

As an efficient transportation mode, High-speed transport infrastructure like High-speed rail, airport and expressway has been developed worldwide recently. On one hand High-speed transport infrastructure partly reflects the transportation infrastructure development level of a country, on the other hand, construction of High-speed transport infrastructure requires huge amount of investment. As a result, when government need to make the future plan about the High-speed transport infrastructure, 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 transport infrastructure for your country?"

In order to answer these questions, a suitable methodology to evaluate the development level of High-speed transport infrastructure which related to geography, demography and economy is essential for decision maker in government and transport 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 mostly 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 transport infrastructure development level of a whole country, not an individual project, so that macroscopic thinking should be applied.

1.2 Research Objective

By reviewing existing methodologies and researches, a comprehensive way of evaluating suitable development level of High-speed transport infrastructure for a whole country hasn't been found. While finding absolute evaluation of High-speed transport infrastructure is difficult, the comparison of High-speed transport infrastructure 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 transport infrastructure of each country under the consideration of geography, demography and economy. Previous research in my laboratory has already researched the comparative methodology about Expressway （IGO, 2010; KONDO, 2011） and Airport (CHIU, 2011). So firstly, I want to construct a model to compare the level of High-speed rail. After finishing the comparison of High-speed rail, the combination of existing models also will be considered.

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 worldwide data to derive the comparative development level and development tendency of High-speed rail in each country. Analyzing the characteristics and change of High-speed rail development.
3. Combining the previous researches of expressway and airport comparative models and making the international multi-transport modes comparison.

1.3 Literature Review

1.3.1 Cost-Benefit Analysis

H. Morisugi(2000)'s paper "Evaluation methodologies of transportation projects in Japan" examines the system and manuals for transportation project evaluation, which are recently introduced for all transportation modes, road, railway, airport and seaport projects in Japan. The manuals aim to evaluate the social significance of projects from the viewpoint of efficiency and equity, by applying a sort of multi-criterion analysis, although adopting the cost benefit analysis as a basic method to evaluate social efficiency. In his research, one of the characteristics of the railway manual is that it evaluates the value of transfer time and congestion relief inside passenger trains for which it recommends the use of either the income approach or RP methods. RP methods are straightforward procedures while the income approach requires a more complex process. Based on the income approach, the value of time is initially determined at 39.3 yen per minute, independent of the trip purpose. The value of time for transfer is then taken as twice as the value of time in the train, based on previous studies. Though the manual also evaluates the impacts in terms of safety, noise, NOx emissions and global warming using the same unit value as that of roads, it does not consider the congestion relief on road traffic.

The Railway Project Evaluation Manual 2005(鉄道プロジェクトの評価手法マニュアル 2005) provides detailed process of Cost-Benefit Analysis in Railway Project and Rail Station Project. The calculation period is from construction period to 30 or 50 years later after project finishing. The object of analysis contains rail user, railway provider, local residents, etc. Main benefit in this manual include：User's Benefit: the change of access and egress time to rail station; the change of total travel time; the reduce of travel cost; the improvement of environment and convenience in the train and station. Provider's Benefit: increase of profit, etc. Local Resident's Benefit: release of congestion in road; reduce the emission of CO_2, NOx; improvement of traffic accident, etc. Cost of the railway provider mainly contains the construction investment, maintenance cost, operation cost, etc. The detailed process of calculation of every benefit and cost is derived in this manual. Some case studies are also presented.

1.3.2 Comparative methodology of Expressway and Airport

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 countries. 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 research. 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 country.

1.3.3 Other Researches

The “The Economic Effects of High Speed Rail Investment” made by Ginés de Rus*(University of Las Palmas, Spain) discusses, within a cost-benefit analysis framework, under which conditions the expected benefits from deviated traffic (plus generated traffic), and other alleged external effects and indirect benefits justify the investment in HSR projects. It pays special attention to intermodal effects and pricing. As the consequence, the engineering of HSR is complicated but its economics is very simple. High proportion of fixed and sunk costs, indivisibilities, long life and asset specificity make this public investment risky, with a very wide range of values for the average cost per passenger-trip. The social profitability of investing public money in this technology depends in principle on the volume of demand to be transported and the incremental user benefit with respect to available competing alternatives. The lack of private participation in HSR projects increases the risk of losing money; or reworded in more precise terms, of losing the net benefits in the best alternative use of public funds. HSR investment may be adequate for some corridors, with capacity problems in their railway networks or with road and airport congestion, but its convenience is closely related to the volume of demand to be attended. Moreover, even in the case of particularly favorable conditions, the net present value of HSR investment has to be compared with other alternatives as road or airport pricing and investment, upgrading of conventional trains, etc.

1.4 High-Speed Rail in the world

The early research of High-speed rail can be traced to 1903. An electrical railcar from Siemens & Halske sped away at 203 km/h on the military railway track between Marienfeld and Zossen in Germany. In 1945, Alejandro Goicoechea, a Spanish engineer, invented a streamlined diesel train that could move on existing tracks and reached the speed of 80 mph(129km/h) by designing both the locomotive and cars with a unique axle system that used one axle set per car.

After Second World War, Japan made breakthrough of High-speed rail. In 1957, the engineers at local private Odakyu Electric Railway in Greater Tokyo area launched the Odakyū 3000 series SE EMU, this train can reach the speed of 145 km/h, which set a world record for narrow gauge trains. After that, Engineers of Japan started planning the intercity dedicated high-speed line. The plan was fast-tracked and the construction was started in 20 April 1959; test runs in 1963 achieved top speed of 256 km/h. In October 1964, just in time for the Tokyo Olympic Games, Japan opened the first modern high speed rail, Tokaido Shinkansen, between Tokyo and Osaka.

Japan's success, rising oil prices, growing environmental concerns, and rising road congestion made contribution to a revival of interest in high-speed rail in Europe. In Europe, high-speed rail started during the International Transport Fair in Munich in June 1965, when DB Class 103 hauled a total of 347 demonstration cars at 200 km/h between Munich and Augsburg. Great Britain introduced Europe's first regular service that travelled above 200 km/h, albeit with a small margin and without building new lines in 1976–1982. In Continental Europe, several countries began to construct new high-speed lines during the 1970s, including Italy's Direttissima between Rome and Florence, Western Germany’s Hannover–Würzburg and Stuttgart–Mannheim lines and France’s Paris–Lyon TGV line (LGV Sud-Est). The LGV Sud-Est was the world’s fastest High-speed rail when it opened in 1983, with maximum speed of 270km/h and an average speed of 214km/h.

After 21st century, other Asian countries like China and South Korea began to development with a rapid speed. Until 2011, the total High-speed rail in operation in the world is 17166 km and there are 8838 km network under construction and 16318 km expansion have been planned.

1.4.1 High-speed rail in Asia

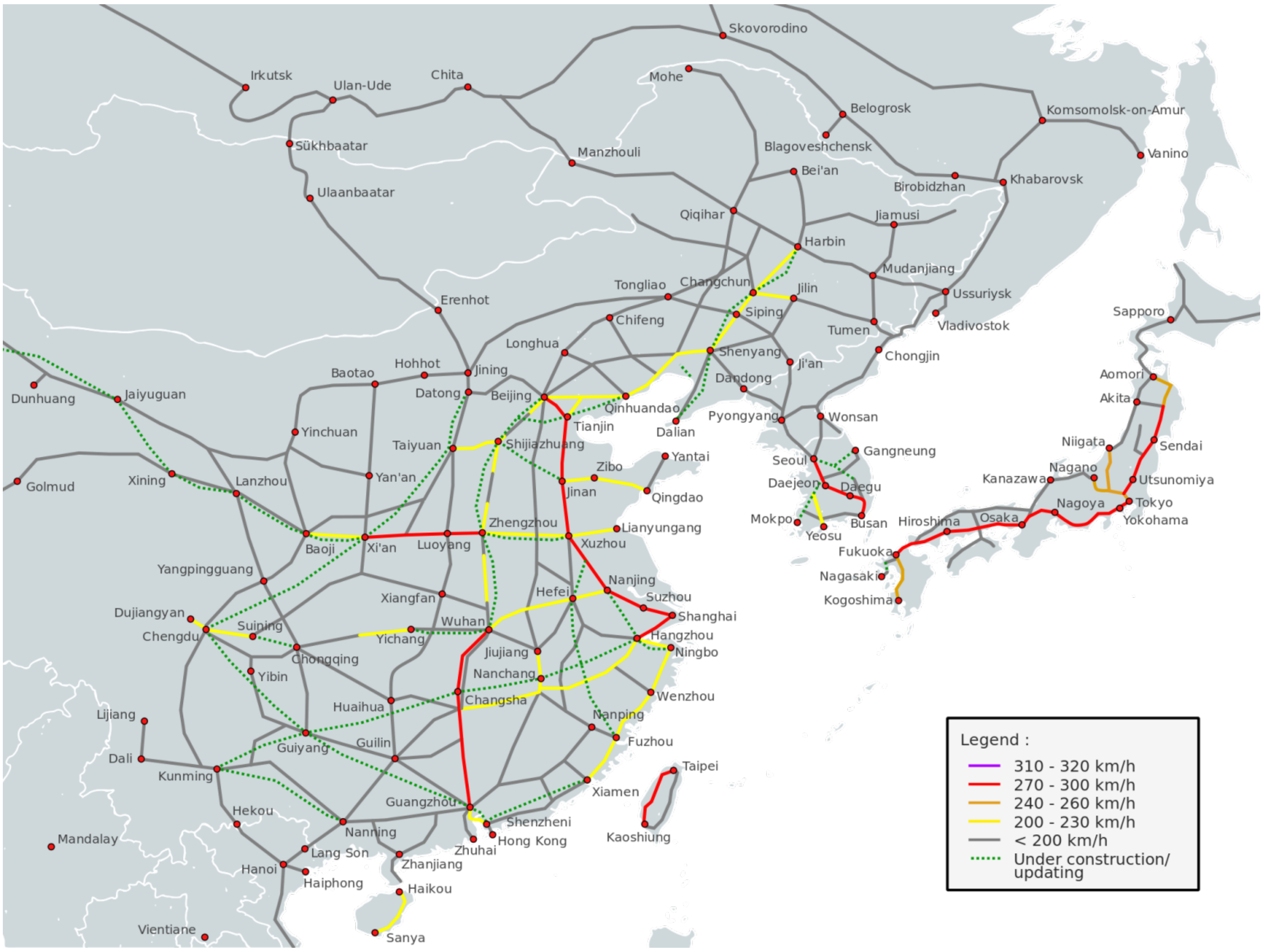

Figure 1 High speed rail in Eastern Asia, 2011

Japan

Japan could be considered the pioneer of modern High-speed rail. The first High-speed rail construction in Japan began in 1959, and in 1964, the world's first modern High-speed line, Tokaido Shinkansen opened to the public, at a speed of 210 km/h. The Tokaido Line's rapid success prompted an extension westward to Hiroshima and Fukuoka (the Sanyo Shinkansen), which was finished in 1975. The hosting of the 1998 Winter Olympics in Nagano gave Japan a precious chance to display its technological skills with the opening of a new High-speed rail line, the Hokuriku Shinkansen from Tokyo to Nagano. Until the completion of Tohoku Shinkansen in 2010 and Kyushu Shinkansen in 2011, Japan's total High-speed rail network in operation have reached 2664km.

On May 2011, JR Central announced the company will start operation of maglev route from 2027 between Tokyo–Nagoya followed by Nagoya–Osaka route by 2045, running at a maximum speed of 505 km/h.

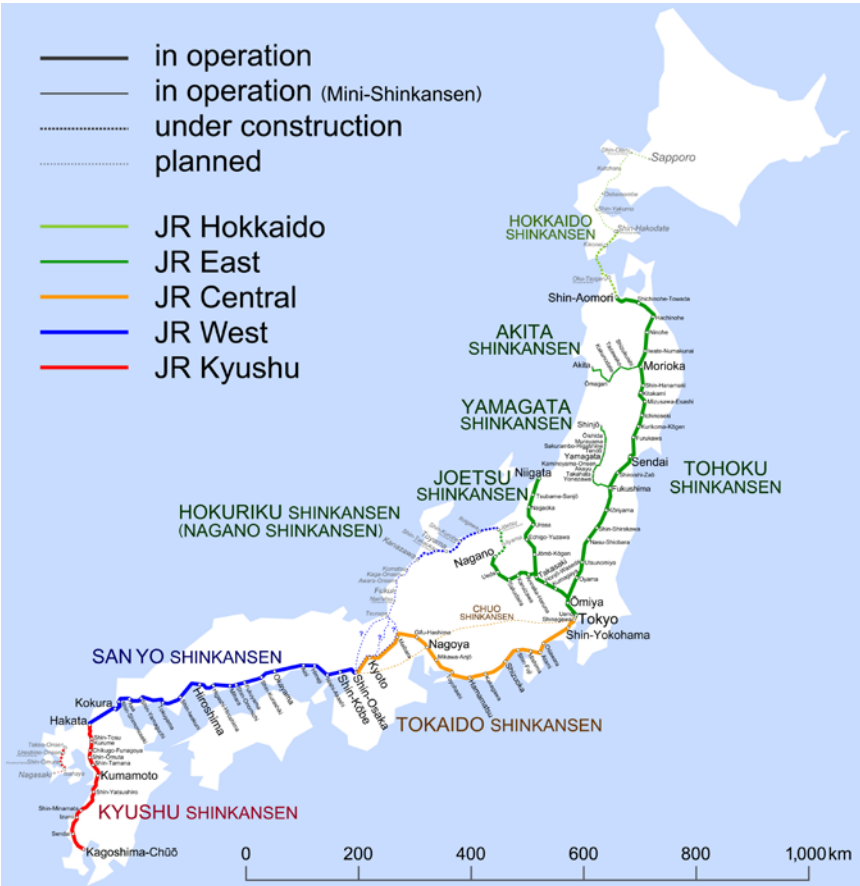

Figure 2 Map of Shinkansen(Japan's High-speed rail) network, 2012

China

According to the Chinese MOR (Ministry of Railway)'s "Mid-to-Long Term Railway Network Plan" (revised in 2008), China’s national high-speed rail grid is composed of 8 high-speed rail corridors, four running north-south and four going east-west, and has a total of 12,000 km.

China's first conventional high-speed line, the Qinshen Passenger Railway (Qinhuangdao-Shenyang), opened in 2003 with a maximum speed of 200 km/h. On 1 August 2008, The Beijing-Tianjin high-speed rail, the first line in China which can support faster than 300 km/h was opened. Currently the fastest CRH Service is on the Wuhan–Guangzhou line, opened on 26 December 2009. The Beijing-Shanghai Express Railway(1,318 km) which connects the most two important cities in China started to be constructed in April 2008, opened on 2011. Until 2011, China’s total High-speed rail network has reached 6299 km in operation, 4339 km under construction and 2901 km under planning.

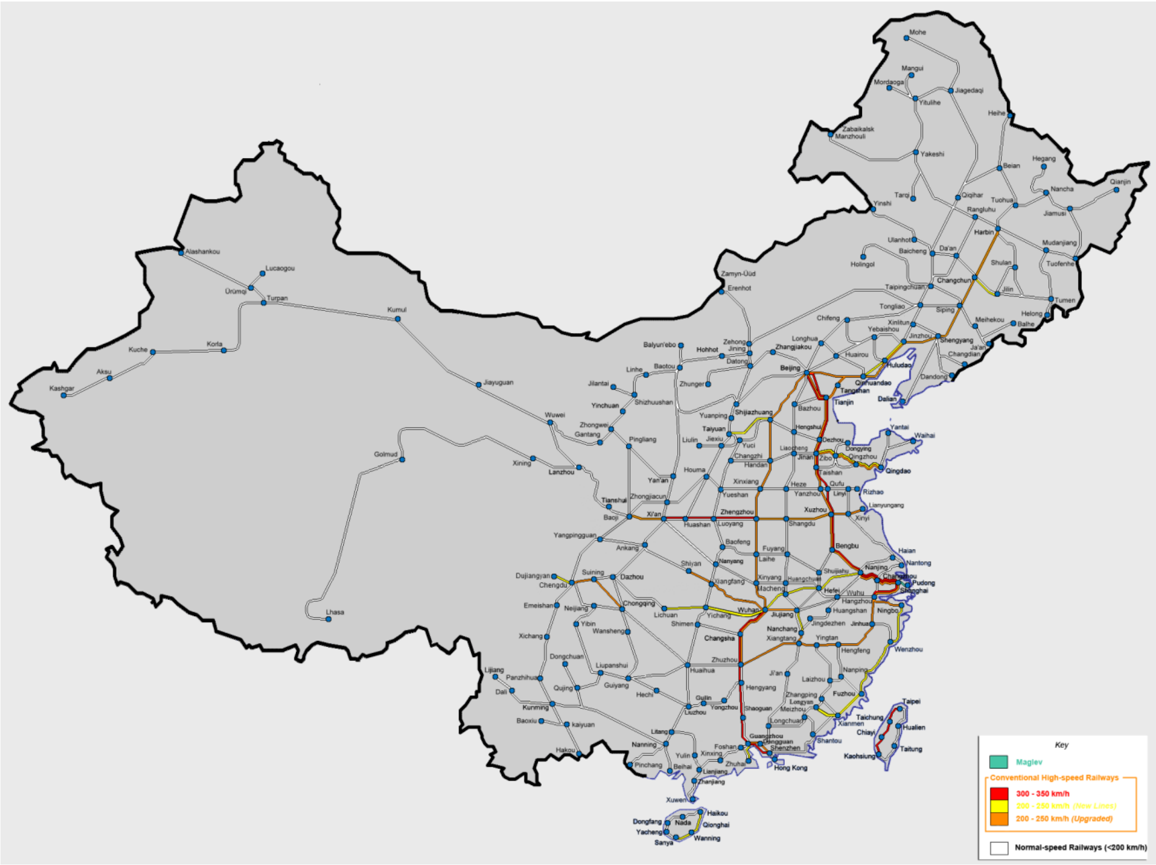

Figure 3 Map of China’s High-speed rail network 2011

South Korea

South Korean's High-speed rail, KTX, became operational in April 2004 from Seoul to Daegu, and South Korea became the third country outside Western Europe to have high speed intercity service, after Japan and the US. After missing forecasts and running deficits in the first year, KTX increased ridership and market share, transporting over 100,000 passengers daily and making a profit for Korail since 2007.

The second phase of the Seoul–Busan line(Daegu to Pusan) was opened on November 1, 2010, with two sections crossing urban areas to be completed by 2014. Construction of a second high-speed line to Mokpo began in December 2009, and is planned to open in 2014. Other new lines and upgraded conventional lines are in various stages of planning or construction, including one to serve the 2018 Winter Olympics in Pyeong Chang. By the end of 2011, South Korea's total High-speed rail network has reached 412 km in operation, 186 km under construction and 49 km under planning.

Figure 4 Korea Train Express map in October 5, 2011

1.4.2 High-speed rail in Europe

Figure 5 High Speed Railway Network in Europe in 2011

France

France is the first European country which had modern High-speed rail in operation. In 1976 the French government funded the TGV project, and construction of the LGV Sud-Est, and in 1981, the LGV Sud-Est from Paris to Lyon opened and TGV started passenger service, this is the first modern High-speed rail line opened in Europe. The success of the first line led to an expansion of the network, with new lines built in the south, west, north and east of the country, extending in every direction from Paris. Further LGVs have opened: the LGV Atlantique (LN2) to Tours/Le Mans (construction begun 1985, in operation 1989); the LGV

Nord-Europe (LN3) to Calais and the Belgian border (construction begun 1989, in operation 1993); the LGV Rhône-Alpes (LN4), extending the LGV Sud-Est to Valence (construction begun 1990, in operation 1992); and the LGV Méditerranée (LN5) to Marseille (construction begun 1996, in operation 2001). The LGV Est (LN6) from Paris to Strasbourg was operational on 15 March 2007, and opened to the public in the summer of 2007. The LGV Perpignan-Figueras (LN7) opened on December 2010. And in 2011 the LGV Rhin-Rhône (LN8) first phase opening. At the end of 2011, France has the second longest high-speed network in Europe, with 1896 km High-speed rail lines in operation, only behind Spain's 2056 km.

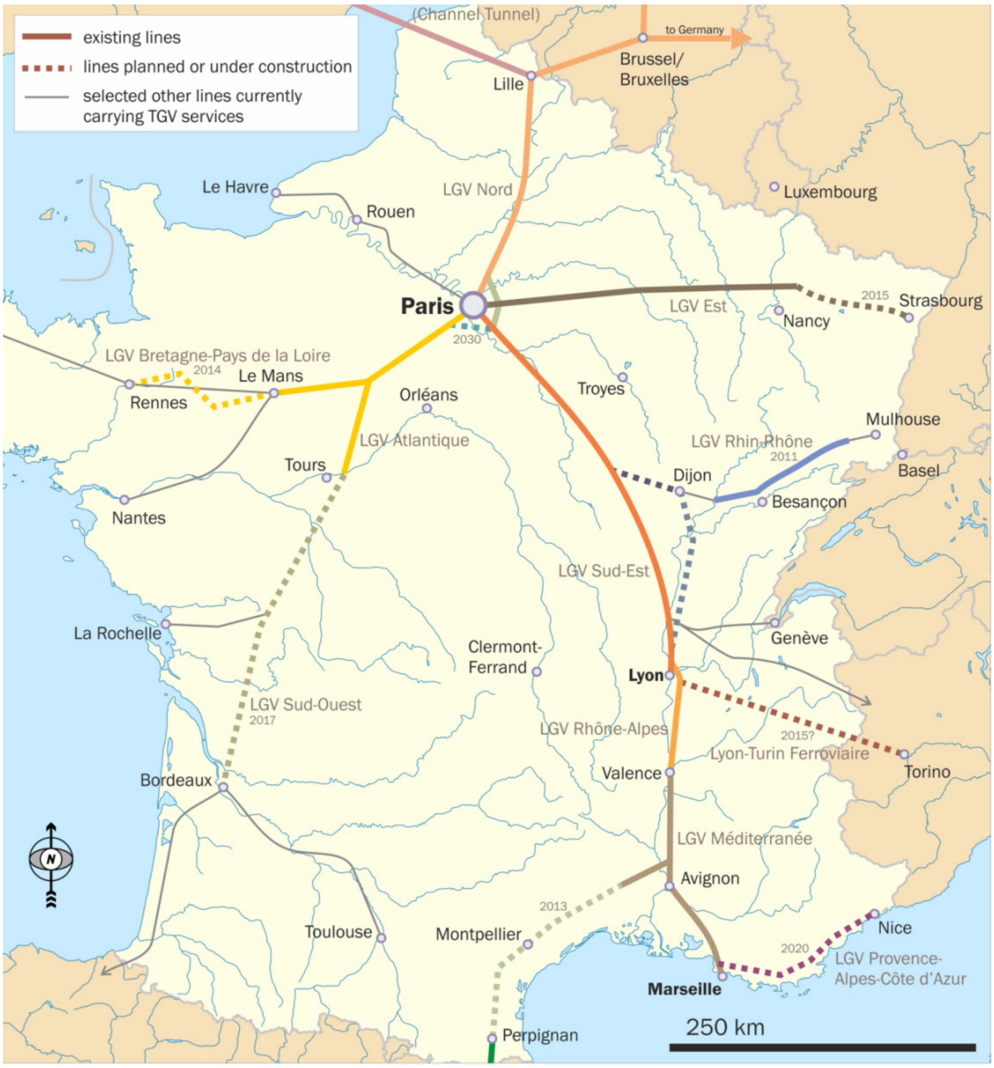

Figure 6 Map of French TGV lines network 2011

Germany

Construction of the first German High-speed rail lines began shortly after that of the French LGVs. However, legal battles caused significant delays, so that the German InterCityExpress (ICE) trains were delayed. In 1988, the first High-speed rail line in Germany was opened from Fulda to Würzburg. The inauguration of ICE and schedule ICE service was started from 1991, which was ten years after French TGV network was established. The first ICE line was from Hannover to Würzburg. At the end of 2011, Germany's total High-speed rail network has reached 1285 km in operation, 378 km under construction and 670 km under planning.

Figure 7 Map of German ICE rail network 2010

Spain

The Spanish High-speed rail, Alta Velocidad Española (AVE) high-speed rail system has been in service since 1992, when the Madrid–Sevilla (Seville) route started running. In order to connect the capital, Madrid, with several of Spain's largest cities, other lines have been constructed, which are the Madrid–Valladolid high-speed rail line(2007), the Córdoba–Málaga high-speed rail line(2007), the Madrid–Barcelona high-speed rail line(2008), the Madrid–Valencia high-speed rail line(2010), and Madrid–Albacete high-speed railway line(2010).

The network is to be greatly expanded during the next decade with most of the Spanish peninsula being connected. The recently completed Madrid-Valencia line brings the total length of the network up to 2056 kilometers, making it the longest in Europe.

Figure 8 Map of Spanish High-speed rail network 2011

1.4.3 High-speed rail In USA

United States currently consists of only one high-speed rail service, Amtrak's Acela Express, runs on the Northeast Corridor from Boston to Washington, D.C. Unlike Asian or European systems, the Acela shares its tracks with conventional rail, and thus is limited to an average speed of 109 km/h for the entire distance with brief segments up to 240 km/h in 362 km.

America's first dedicated high-speed rail infrastructure is likely to be in California, consisting of a high speed line between Anaheim and San Francisco via Los Angelesand San Jose. The line is scheduled to begin construction by September 2012 in the Central Valley. The new line planned for construction in California would have a top speed in excess of 240 km/h and is classified as a High-Speed Rail–Express corridor.

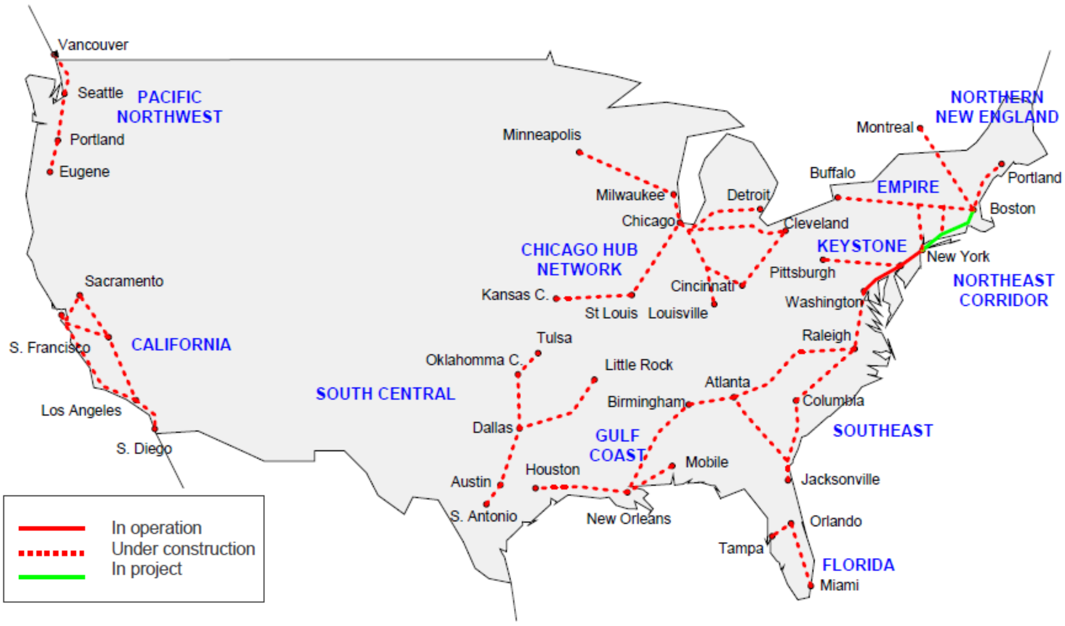

Figure 9 Map of USA High-speed rail network 2010

Chapter 2. Methodology

2.1 Basic Theory of High-speed rail Comparative Model

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 Operation 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: Operation Speed of High-speed rail;

$v_{N:}$ Accessing Speed(to High-speed rail network).

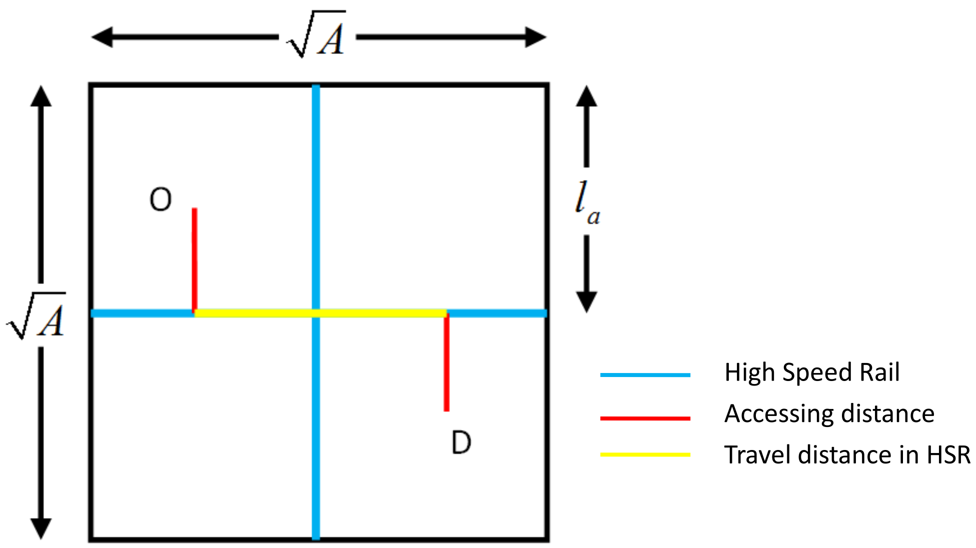

Figure 10 Simplification of country and High-speed rail network

Under the assumptive network of High-speed rail, the interval of High-speed rail network l_a can be calculated as $\frac{\sqrt{A}}{l_a} \times 2 \times \sqrt{A} \approx L \Rightarrow l_a = \frac{2A}{L}$. 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 $k\frac{A}{Lv_N}$, where 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

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

Assume that $\frac{1}{v_N}-\frac{1}{V}=\frac{1}{\Delta v}$, $\frac{1}{\Delta v}$ is a constant; Time value $w = k_w I$, k_w: constant;

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

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

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; $v_{N:}$ Accessing Speed(to High-speed rail network).

Besides, Construction Cost= Unit Cost×Length of High-speed rail=cL;

Where 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

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

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

$$\begin{cases} \dfrac{\partial TC}{\partial L} = k_b \dfrac{A}{\Delta v} PI \dfrac{\partial}{\partial L}\left(\dfrac{1}{L}\right) + c = 0 & (4) \\ \dfrac{\partial TC}{\partial V} = k_a PI \dfrac{d}{dV}\left(\dfrac{1}{V}\right) + L\dfrac{dc}{dV} = 0 & (5) \end{cases}$$

total cost will be minimal.

2.1.1 Unit Cost of High-speed rail in different country

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 43 lines in 11 countries are collected, the detail information is shown in table 8 in Appendix.

Influential factors of unit cost are supposed as:

1). 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 lv.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.

2). 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.

3). 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.

4). Operation Speed. According to current technology, higher speed of High-speed rail need higher safety control and advanced technology, it leads to the increase of construction cost.

Regression model is picked as linear model $y=ax_1+bx_2+c$ and unlinear exponential model $y=ax_1^b x_2^c$. By means of SPSS, the result of linear regression and unlinear regression is shown as following：

Linear Function: $UC=a+bx_1+cx_2+\ldots$

Table 1 Regression Result of linear function

Parameter	Value	T value	P value	R^2
Constant	-22.169			0.738
GDP per Capita (US 1000$)	1.050	6.622	0.000	
Population density(people/km2)	0.095	4.890	0.000	
Earquake Index	20.404	4.095	0.000	

Linear Function: $c=k+1.05I+0.095Pd+20.404EI$, R^2 is 0.738

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

Unlinear Function: $UC=k*A^aB^bC^c\ldots$

Table 2 Regression Result of unlinear function

Parameter	Value	T value	P value	R^2
Constant	$e^{-14.233}$			0.773
Operating Speed (km/h)	1.394	2.471	0.018	
GDP per Capita (US 1000$)	0.797	5.813	0.000	
Population density(people/km2)	1.161	6.752	0.000	
Average living area per person（100m2）	0.277	4.698	0.000	

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

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

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

$$\text{Unit Cost: } c = k \times I^{0.797} \times V^{1.394} \times Pd^{1.161} \times AL^{0.277} \qquad (6)$$

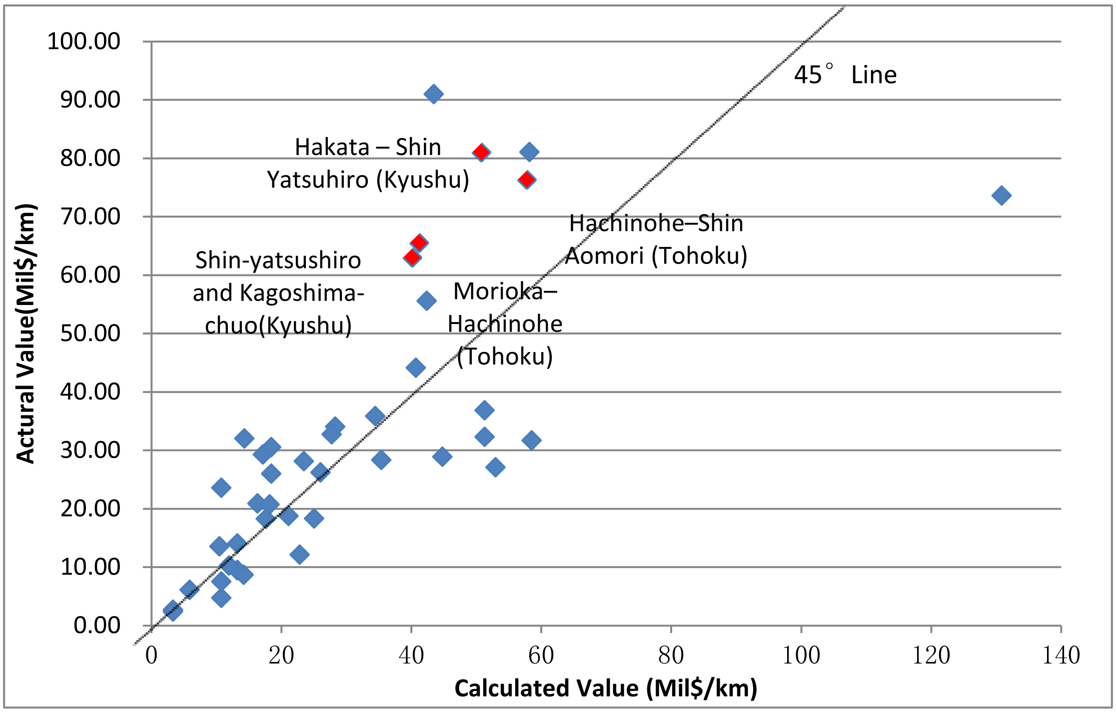

Figure 11 The relation between Calculated Value of Unit cost and Actual Unit cost

2.2 Deriving Comparative development level index

For the purpose of easy calculation, set $c = kc'V^d$, therefore,

$$\begin{cases} \dfrac{\partial TC}{\partial L} = k_b \dfrac{A}{\Delta v} PI \dfrac{\partial}{\partial L}\left(\dfrac{1}{L}\right) + c = k_{b1} \dfrac{API}{L^2} + k_{b2} c' V^d = 0 & (7) \\ \dfrac{\partial TC}{\partial V} = k_a lPI \dfrac{d}{dV}\left(\dfrac{1}{V}\right) + L \dfrac{dc}{dV} = k_{a1} \dfrac{PI}{V^2} + k_{a2} c' LV^{d-1} = 0 & (8) \end{cases}$$

Where k_a, k_b are constants.

$$\Rightarrow \begin{cases} L^* = k_L \dfrac{P^{\frac{1}{d+2}} A^{\frac{d+1}{d+2}} I^{\frac{1}{d+2}}}{c'^{\frac{1}{d+2}}} & (9) \\ V^* = k_V \dfrac{P^{\frac{1}{d+2}} I^{\frac{1}{d+2}}}{A^{\frac{1}{d+2}} c'^{\frac{1}{d+2}}} & (10) \end{cases}$$

Where L^*, V^*: 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.

$$\begin{cases} \alpha_L = \dfrac{L}{L^*} = \dfrac{L}{k_L \dfrac{P^{\frac{1}{d+2}} A^{\frac{d+1}{d+2}} I^{\frac{1}{d+2}}}{c'^{\frac{1}{d+2}}}} & (11) \\ \alpha_V = \dfrac{V}{V^*} = \dfrac{V}{k_V \dfrac{P^{\frac{1}{d+2}} I^{\frac{1}{d+2}}}{A^{\frac{1}{d+2}} c'^{\frac{1}{d+2}}}} & (12) \end{cases}$$

Where k_L and k_V are constants.

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 $\dfrac{\alpha_{Li}}{\alpha_{L0}}, \dfrac{\alpha_{Vi}}{\alpha_{V0}}$ as the comparative development level index of country i,

$$\begin{cases} \dfrac{\alpha_{Li}}{\alpha_{L0}} = \dfrac{L_i}{L_i^*} \Big/ \dfrac{L_0}{L_0^*} = \dfrac{L_i}{L_0} \Big/ \dfrac{L_i^*}{L_0^*} & (13) \\ \dfrac{\alpha_{Vi}}{\alpha_{V0}} = \dfrac{V_i}{V_i^*} \Big/ \dfrac{V_0}{V_0^*} = \dfrac{V_i}{V_0} \Big/ \dfrac{V_i^*}{V_0^*} & (14) \end{cases} ,.$$

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

$$\begin{cases} r_L = \dfrac{\alpha_{Li}}{\alpha_{L0}} = \dfrac{r_{EL}}{r_{NL}}, r_{EL} = \dfrac{L_i}{L_0}, r_{NL} = \dfrac{L_i^*}{L_o^*} & (15) \\ r_V = \dfrac{\alpha_{Vi}}{\alpha_{V0}} = \dfrac{r_{EV}}{r_{NV}}, r_{EV} = \dfrac{V_i}{V_0}, r_{NV} = \dfrac{V_i^*}{V_o^*} & (16) \end{cases}$$

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

$$\Rightarrow \begin{cases} L^* = k_L \dfrac{P^{0.295} A^{0.705} I^{0.295}}{c'^{0.295}} & (17) \\ V^* = k_v \dfrac{P^{0.295} I^{0.295}}{A^{0.295} c'^{0.295}} & (18) \end{cases}$$

$$\begin{cases} \alpha_L = \dfrac{L}{L^*} = \dfrac{L}{k_L \dfrac{P^{0.295} A^{0.705} I^{0.295}}{c'^{0.295}}} & (19) \\ \alpha_V = \dfrac{V}{V^*} = \dfrac{V}{k_v \dfrac{P^{0.295} I^{0.295}}{A^{0.295} c'^{0.295}}} & (20) \end{cases}$$

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

Comparative Development Level r_L, r_V are

$$\begin{cases} r_L = \dfrac{\alpha_{Li}}{\alpha_{L0}} = \dfrac{r_{EL}}{r_{NL}} = \dfrac{\dfrac{L_i}{L_0}}{\dfrac{P_i^{0.295} A_i^{0.705} I_i^{0.295}}{c_i'^{0.295}} \Big/ \dfrac{P_0^{0.295} A_0^{0.705} I_0^{0.295}}{c_o'^{0.295}}} & (21) \\ r_V = \dfrac{\alpha_{Vi}}{\alpha_{V0}} = \dfrac{r_{EV}}{r_{NV}} = \dfrac{\dfrac{V_i}{V_o}}{\dfrac{P_i^{0.295} I_i^{0.295}}{A_i^{0.295} c_i'^{0.295}} \Big/ \dfrac{P_0^{0.295} I_0^{0.295}}{A_0^{0.295} c_0'^{0.295}}} & (22) \end{cases}$$

2.3 Comparative Coordinate Axis

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.

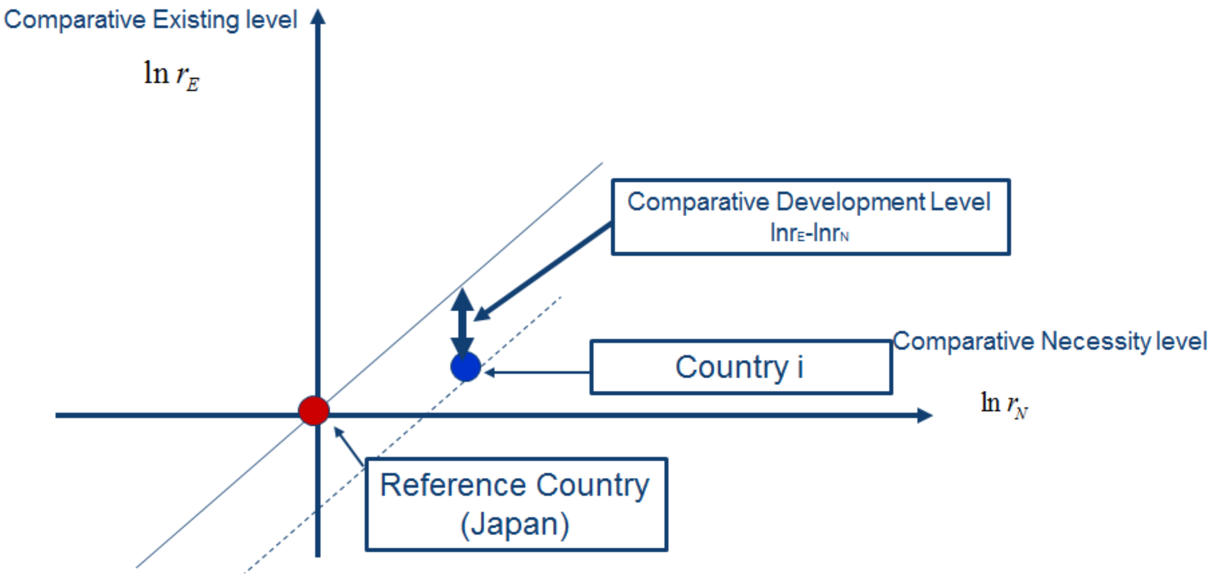

Figure 12 Coordinate axes of comparative development level

From the figure 12, 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, two countries which have the same comparative development level will be in the same 45° line. If country i is under the 45° line of reference country, it means the development level of country i is lower than reference country. Besides, the country with high necessity level is in the right part and the country with high exiting level is located in high position. This normalized approach enables to provide relative information of each country in the comparison.

Chapter 3. Result and Analysis

3.1 Countries and Areas in the Comparison

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 UIC 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 fact that High-speed rail in China and USA are only 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, Ganshu, 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.)

Figure 13 Area of East China

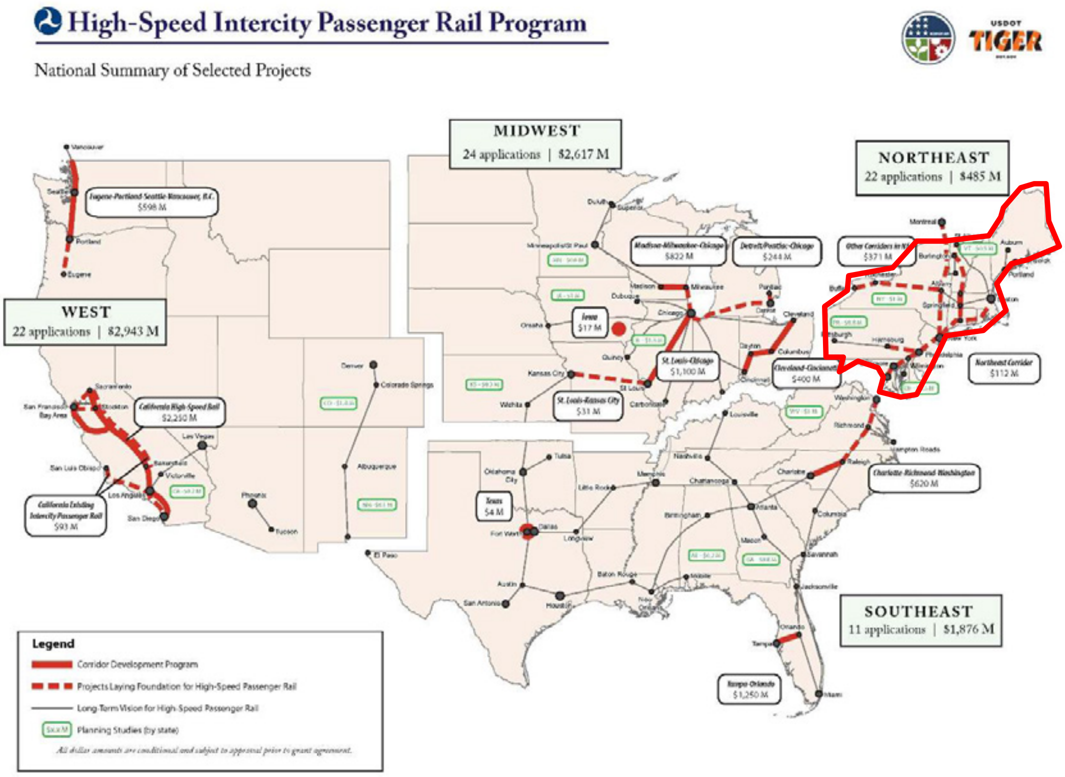

Figure 14 Area of Northeast USA

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 .

Table 3 Condition of High-speed rail by country(2011)

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

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

3.2 Worldwide Comparison Result and Analysis

3.2.1 Result of Network Length

Based on above-mentioned coordinate axes, the result of international comparison of High-speed rail network length can be represented as following:

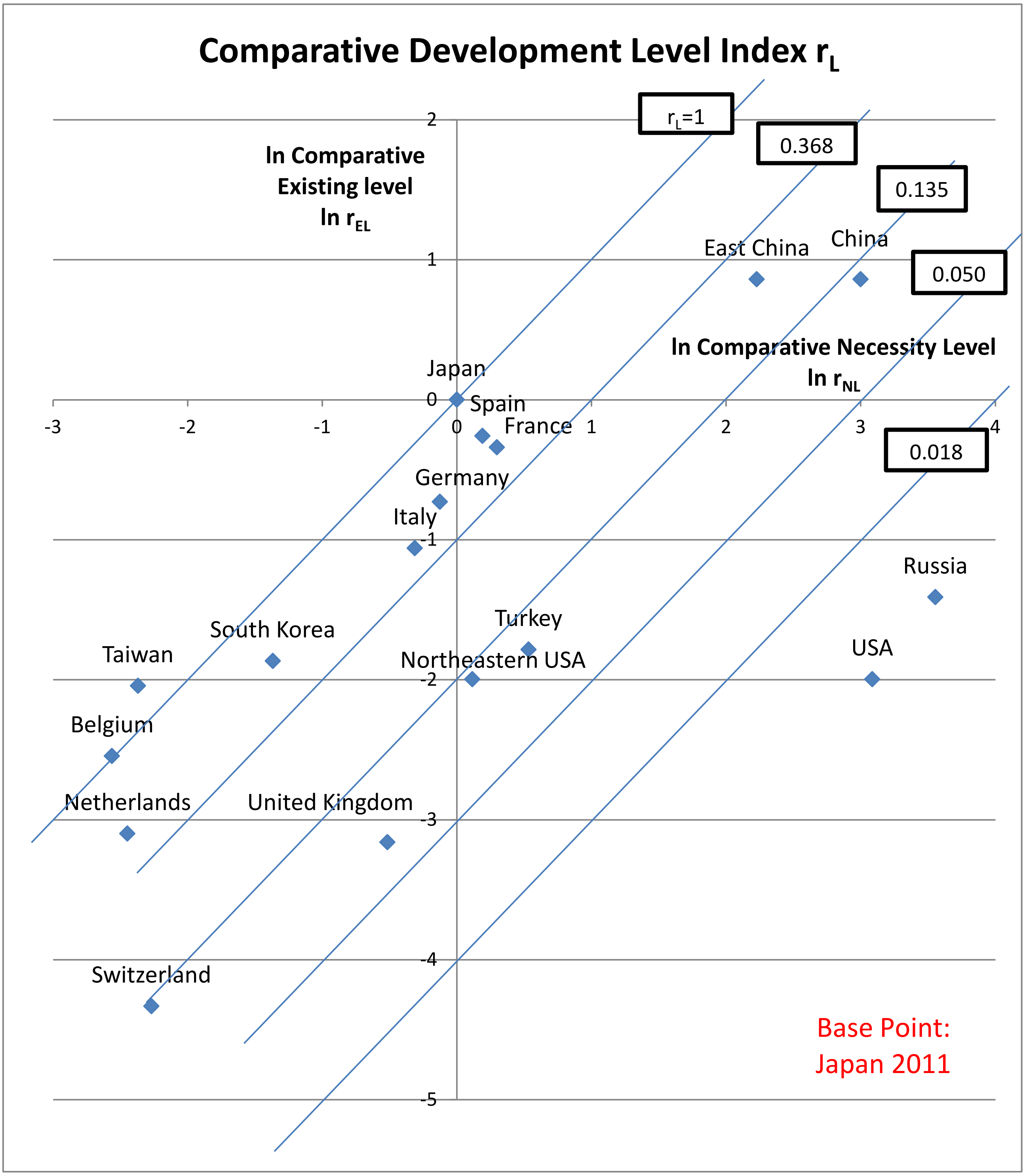

Figure 15 Comparison of comparative length development level of 2011

Table 4 The result of comparative development index of length r_L

Country or Area	Comparative Development Level rL	High speed line in operation (Km)	Country or Area	Comparative Development Level rL	High speed line in operation (Km)
Taiwan	1.386	345	East China	0.256	6299
Belgium	1.012	209	Switzerland	0.126	35
Japan	1.000	2664	Northeastern USA	0.122	362
Spain	0.639	2056	China	0.117	6299
South Korea	0.603	412	Turkey	0.099	447
Germany	0.547	1285	United Kingdom	0.071	113
France	0.527	1896	Russia	0.007	650
Netherlands	0.520	120	USA	0.006	362
Italy	0.473	923			

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 1st 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 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. 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 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 big countries like China, Russia and USA have high necessity level while relatively small countries like Belgium and Netherlands have low level of necessity. 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.

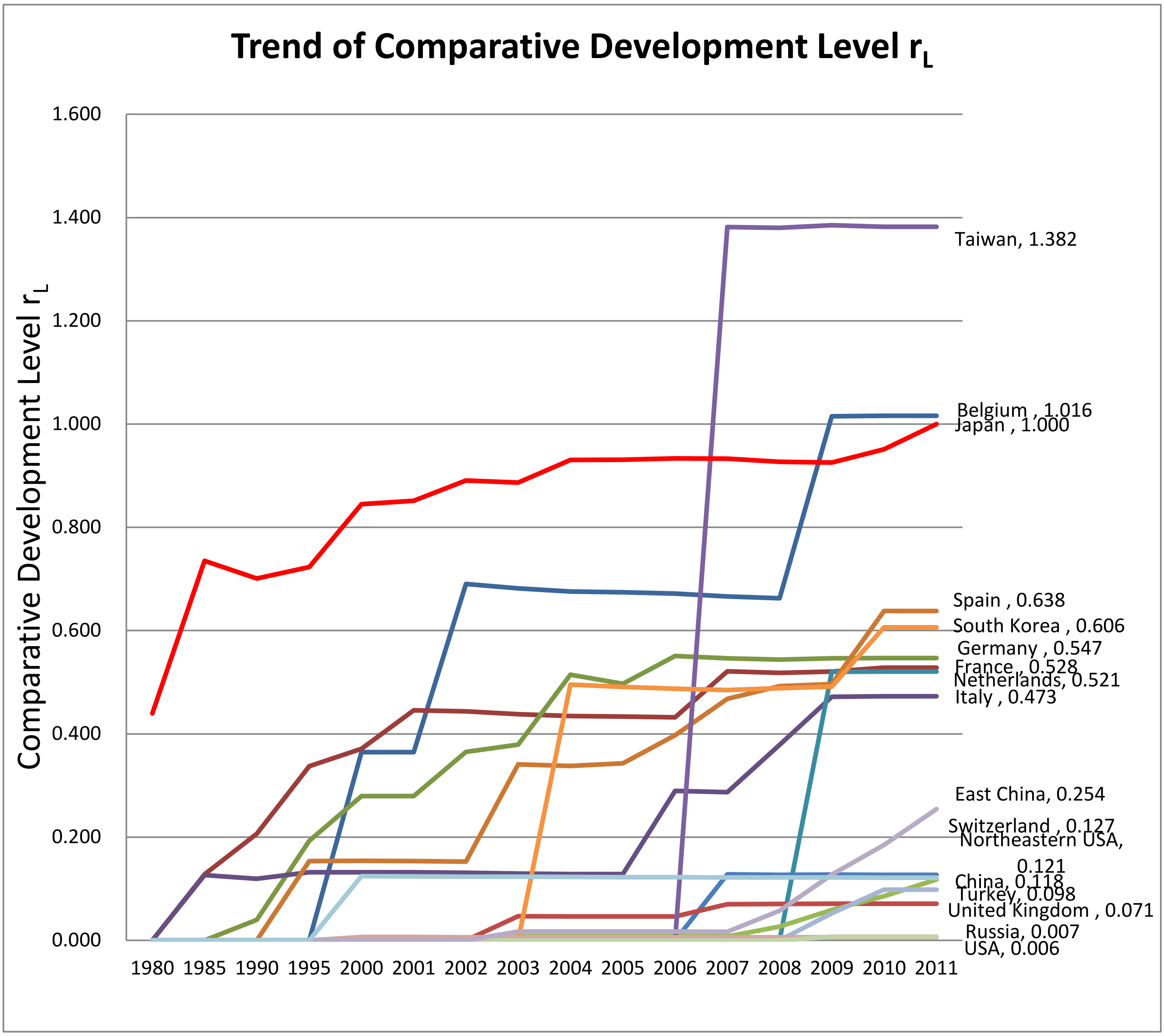

Figure 16 Trend of Comparative Development Level r_L

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. 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.

3.2.2 Result of Operation Speed

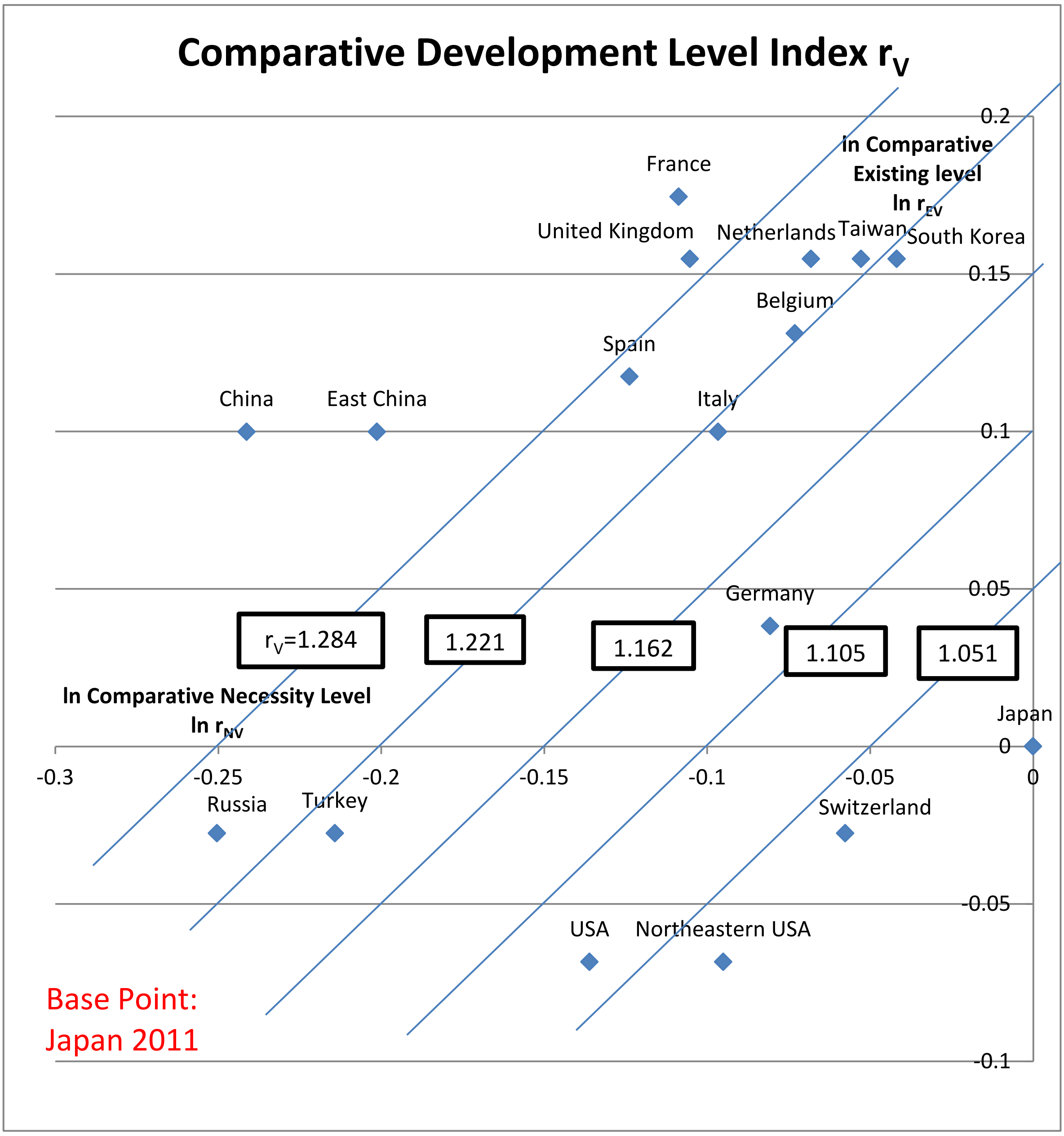

Figure 15 Comparison of comparative speed development level of 2011

Table 5 The result of comparative development index of length r_V

Country or Area	Comparative Development Level rV	Average speed in operation (Km/h)	Country or Area	Comparative Development Level rV	Average speed in operation (Km/h)
China	1.394	284	Italy	1.217	284
East China	1.358	284	South Korea	1.215	300
France	1.325	306	Turkey	1.211	250
United Kingdom	1.295	300	Germany	1.126	267
Spain	1.274	289	USA	1.071	240
Netherlands	1.249	300	Switzerland	1.032	250
Russia	1.238	250	Northeastern USA	1.020	240
Taiwan	1.234	300	Japan	1.000	257
Belgium	1.222	293			

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 Japan2011(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 located 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.

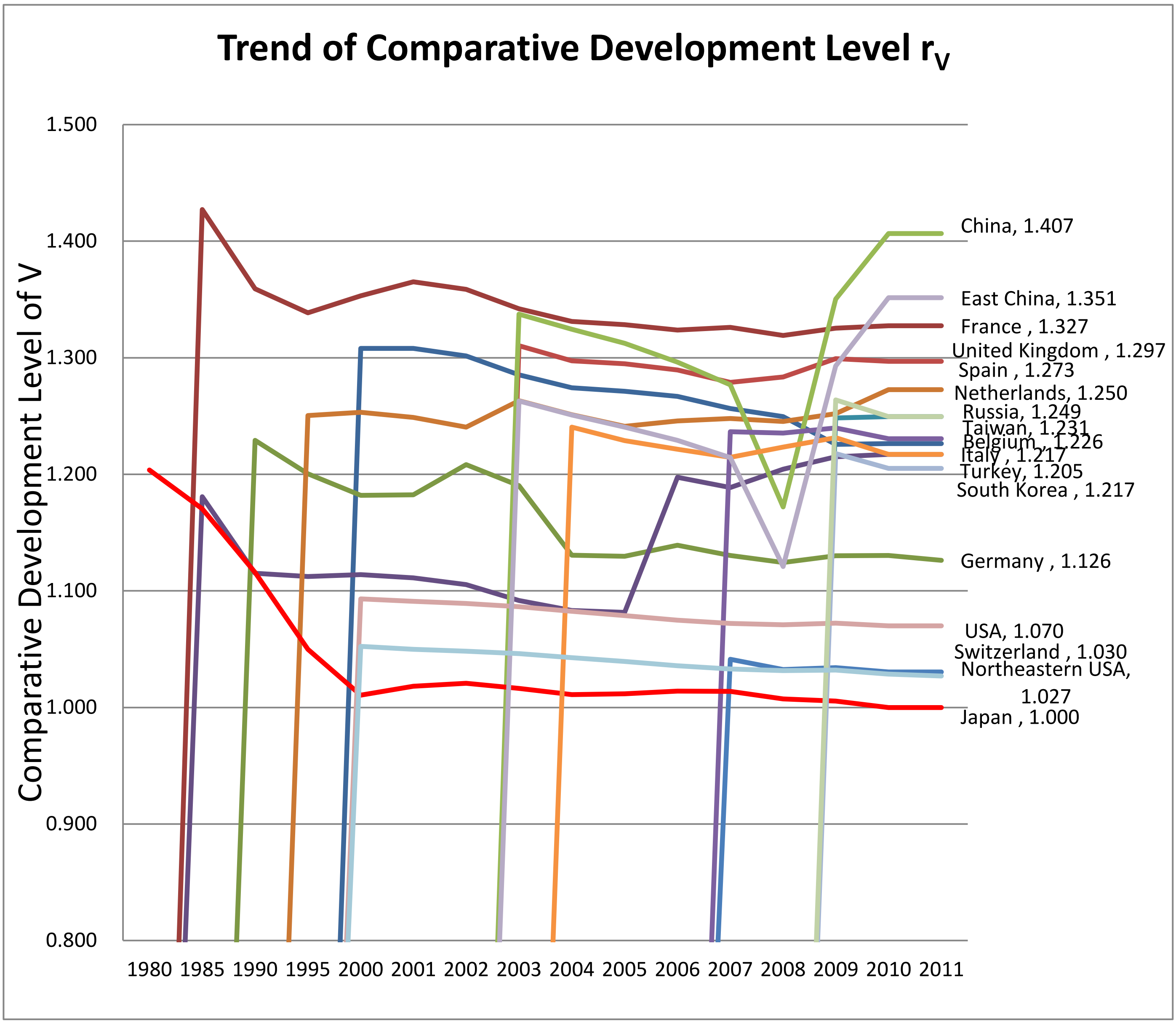

Figure 16 Trend of Comparative Development Index r_V

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.

3.3 Regional Comparison in Japan

In order to understand the regional development level of High-speed rail in Japan, the Japan's regional data and time series data was applied in the model to do the compassion.

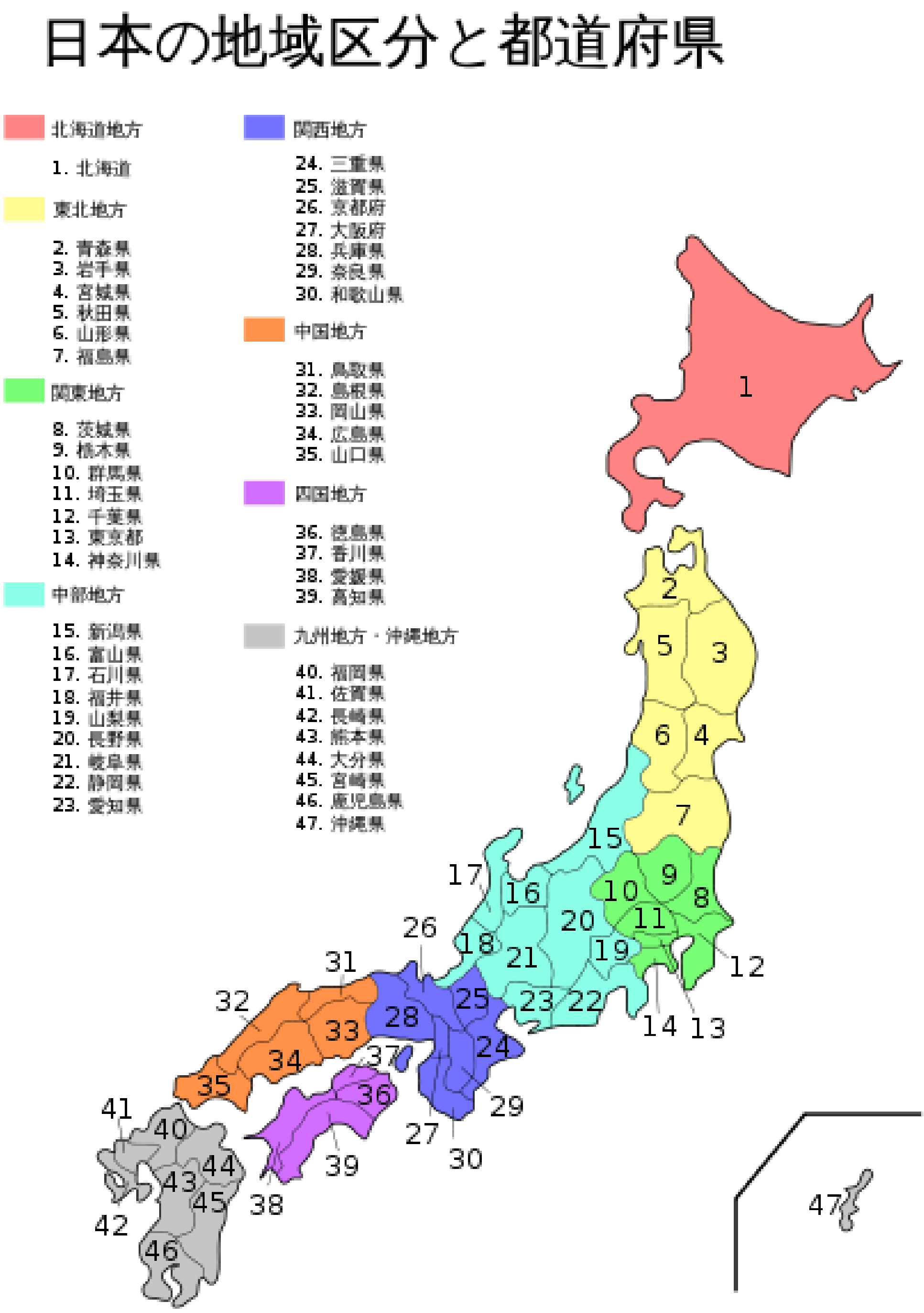

Figure 17 Japan's regional division

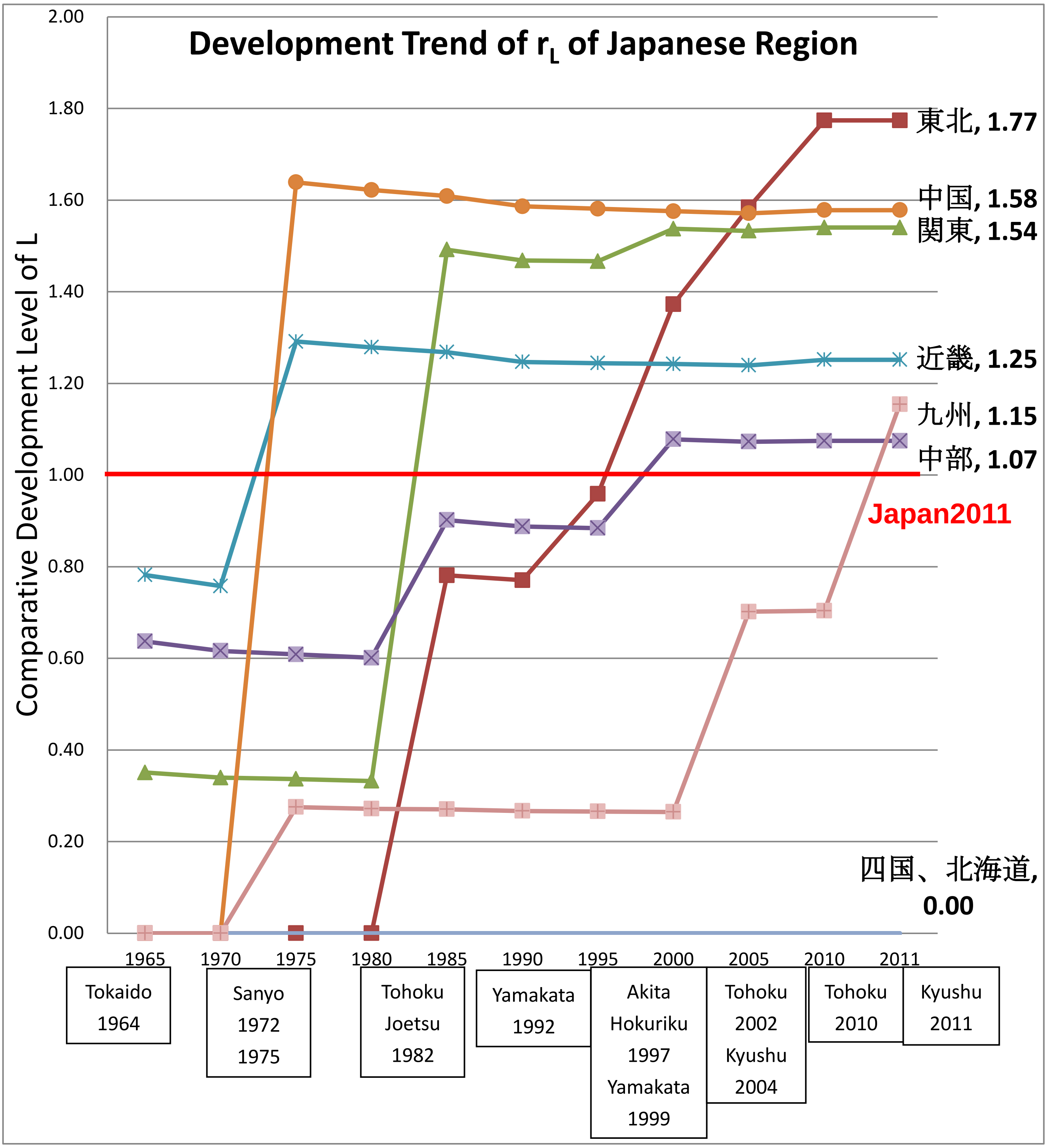

Figure 18 Comparative development level index r_L by region of Japan from 1965 to 2011

The result of r_L shows that all the regions which have High-speed rail in operation have higher development level than Japan's total level in 2011. Tohoku area has the highest development level of network length in Japan, while Sikoku and Hokkaido haven’t built High-speed rail network until 2011. Kanto, Kinki and Chubu areas led the High-speed rail development in Japan since the first line, Tokaido Shinkansen opened in 1964. After Sanyo Shinkansen finished in 1975, Chubu area became the highest level region in Japan until Tohoku region passed it by the completion of Tohoku Shinkansen. By the end of 2011, the completion of Kyushu Shinkannsen made Kyusyu’s level higher than Japan’s total level.

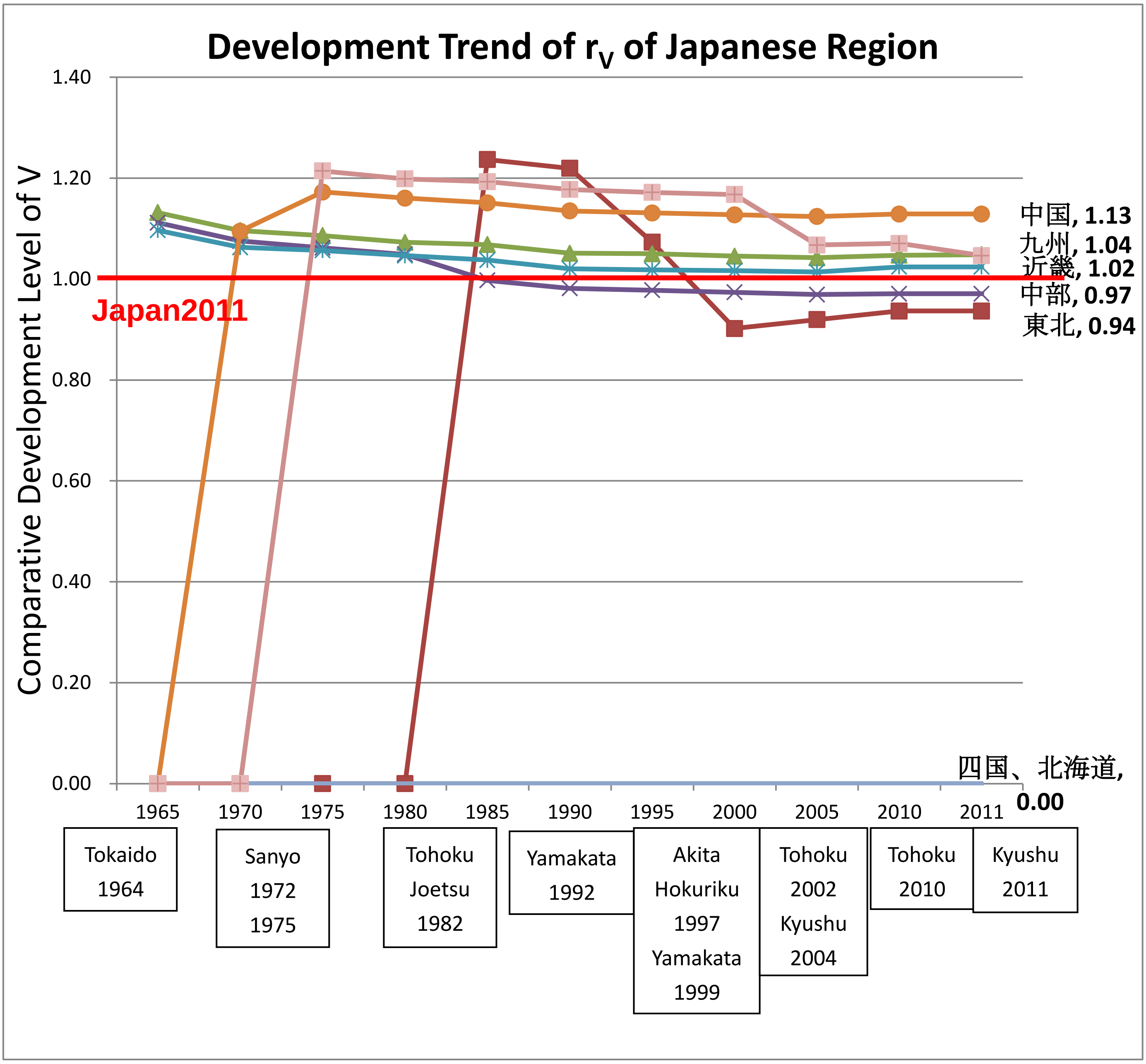

Figure 19 Comparative development level index r_V by region of Japan from 1965 to 2011

According to the result of r_V, all the regions in Japan which have High-speed rail in operation have similar development level of speed, and the basic trend of development level is decreasing from 1965.

3.4 Passenger Number Considered Model

In the above-mentioned model, time cost is the travel cost of all population by using the High-speed rail. However, in one country, the people using High-speed rail is limited. Hereby, time cost of only High-speed rail passenger is considered to be applied into the model instead of time cost of all population. This chapter is trying to compare the difference between these two considerations.

The annual ridership(2009) of every country is shown in following table.

Table 5 Population and Annual Ridership(2009) of each country

Country/Area	Population	Passenger of High-speed rail	Passenger/Population
Belgium	10866560	9561000	0.87985526
France	64876618.4	114395000	1.76327008
Germany	81635580	73709000	0.90290288
Italy	60574530	33377000	0.55100716
Netherlands	16622560	6005000	0.36125603
Spain	46217400	28751000	0.62208173
United Kingdom	62246610	9220000	0.14812052
China(2010)	1338300000	179580000	0.13418516
Taiwan	23061689	32349000	1.40271599
Japan	127380000	288836000	2.26751452
South Korea	48875000	37477000	0.76679284
Turkey	75705147	942000	0.01244301
USA	309712000	3218718	0.01039262
Russia	141750000	7000000	0.04938272
East China	1251420000	179580000	0.14350098
Northeastern USA	60867587	3218718	0.05288066

In passenger model, population in the time cost equation changes to the annual passenger number. By applying the passenger number into the model, time cost equation changes to the following equation.

Time cost(for Passenger)=Total time×Time vale= $k_a \frac{l}{V} P_r I + k_b \frac{A}{L\Delta v} P_r I$,

Where ka, kb: Constant; Pr: Annual passenger number.

As the result, Total Cost $TC = k_a \frac{l}{V} P_r I + k_b \frac{A}{L\Delta v} P_r I + cL$ (23)

Through the same calculation as above model, the optimal development level of L and V is

$$\begin{cases} \alpha_L' = \frac{L}{L^*} = \frac{L}{k_L \frac{P_r^{0.295} A^{0.705} I^{0.295}}{c'^{0.295}}} & (24) \\ \alpha_V' = \frac{V}{V^*} = \frac{V}{k_v \frac{P_r^{0.295} I^{0.295}}{A^{0.295} c'^{0.295}}} & (25) \end{cases}$$

Comparative Development Level r_L, r_V are

$$\begin{cases} r_L = \frac{\alpha_{Li}}{\alpha_{L0}} = \frac{r_{EL}}{r_{NL}} = \frac{\frac{L_i}{L_0}}{\frac{P_{ri}^{0.295} A_i^{0.705} I_i^{0.295}}{c_i'^{0.295}} \Big/ \frac{P_{r0}^{0.295} A_0^{0.705} I_0^{0.295}}{c_o'^{0.295}}} & (26) \\ r_V = \frac{\alpha_{Vi}}{\alpha_{V0}} = \frac{r_{EV}}{r_{NV}} = \frac{\frac{V_i}{V_o}}{\frac{P_{ri}^{0.295} I_i^{0.295}}{A_i^{0.295} c_i'^{0.295}} \Big/ \frac{P_{r0}^{0.295} I_0^{0.295}}{A_0^{0.295} c_0'^{0.295}}} & (27) \end{cases}$$

Putting above r_L, r_V into use, the results of comparison are as following

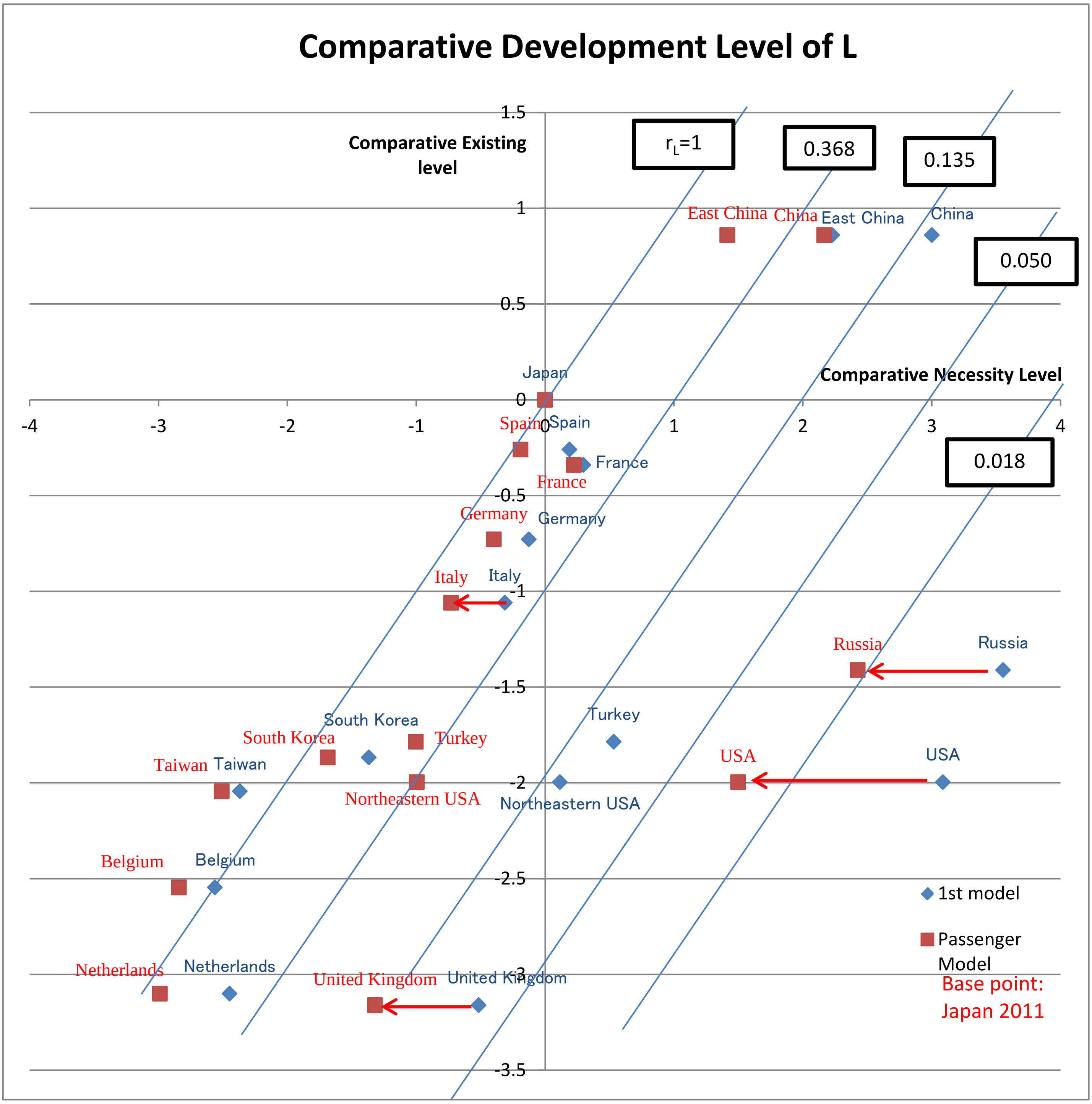

Figure 20 Comparison of comparative development level index r_L of 2011 by 2 models

From the result, the comparative development level of every country or area except Japan increased. Compare with the 1st model, the necessity level of Japan must be higher than other countries because the ratio of ridership/population of Japan is the highest among all the area. It caused the reduction of comparative necessity level of other countries, which lead to the increase of comparative development level. The country like USA which have big gap between 2 models means their ratio of ridership/population is much lower than Japan.

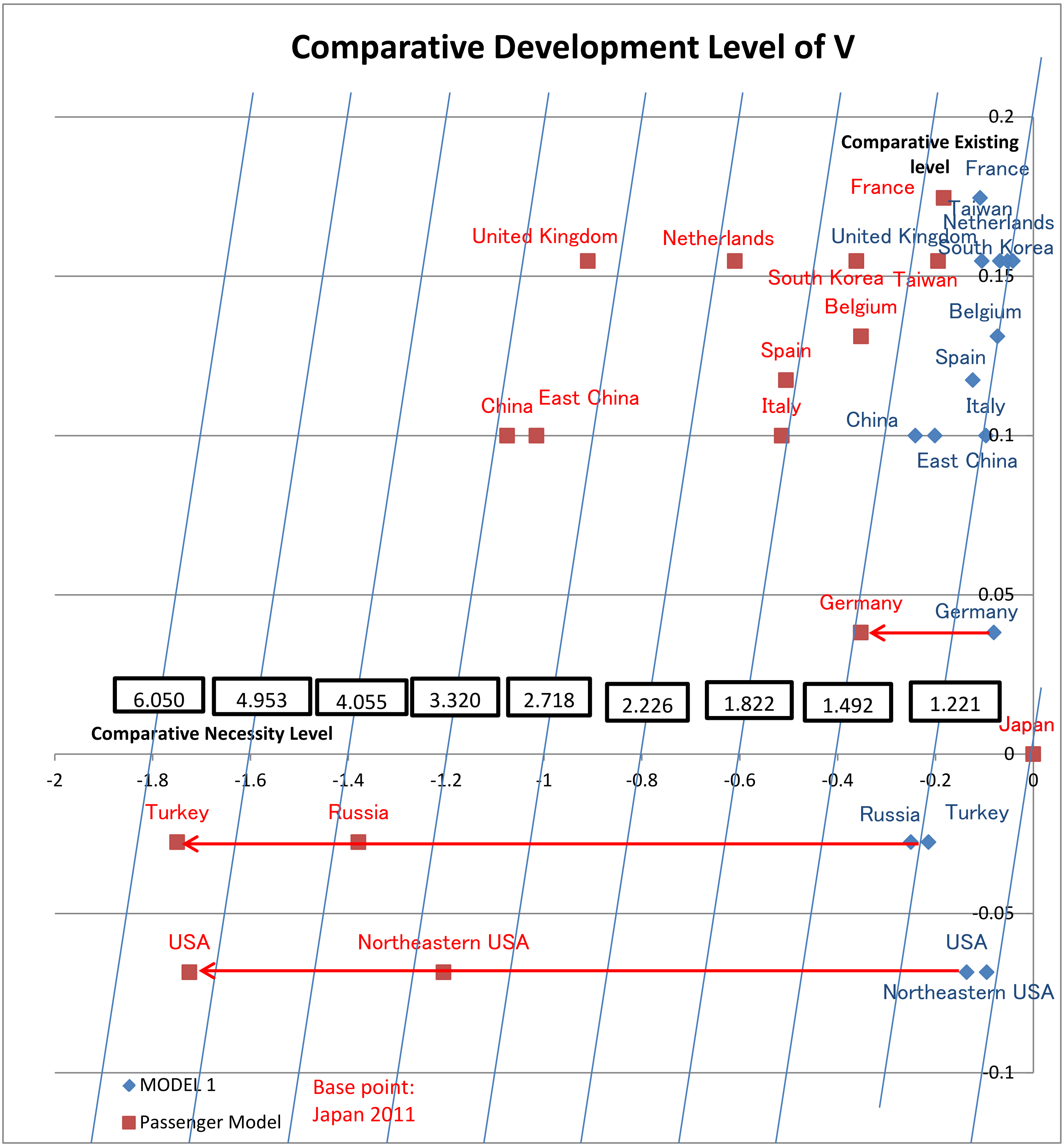

Figure 21 Comparison of comparative development level index r_V of 2011 by 2 models

In the comparison of comparative development level index r_V by 2 models, the comparative development level of every country or area except Japan increased. Especial USA and Turkey have more than 5 times development level of Speed than Japan in passenger model, which is unacceptable and unreasonable based on the reality. The possible reason of this problem is that operation speed doesn't have strong effect on the annual ridership, which means the necessity level of speed is not strongly related to the passenger number. In other words, passenger model is not suitable to apply to the comparison of development level of speed.

Chapter 4. Multi-Transport Modes Comparison

4.1 Previous Model

As mentioned before, the previous researches in my laboratory have studied the comparative methodology of Expressway and Airport. Basically, spatial accessibility is an important comparative index in their researches, therefore, I want to combine the accessibility index of all the three transport modes and make the international multi-transport mode comparison.

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. In his research, the optimal length of Expressway network is $L^* = k\sqrt{\frac{PAI}{c}}$ (Where A: Area of the country; P: Population; I: GDP per capita; c: Unit Construction Cost; k: constant).

Based on IGO's research, Kondo(2011) considered the relationship between economy and traffic demand and revised the model. The traffic demand in Kondo's study is $D = k \times I^{0.5} \times P$ （P: Population; I: GDP per capita; k: constant). After this revision, the optimal length of Expressway network changes to $L^* = k\sqrt{\frac{DAI}{c}} = k\sqrt{\frac{PAI^{1.5}}{c}}$ (Where A: Area of the country; P: Population; I: GDP per capita; c: Unit Construction Cost; k: constant). The comparative development level index of Expressway network length is

$$r_{Exp} = \frac{\frac{L_i}{L_o}}{\sqrt{\frac{P_i A_i I_i^{1.5}}{c_i}} \Big/ \sqrt{\frac{P_o A_o I_o^{1.5}}{c_o}}} \tag{28}$$

Where L_i: the Expressway network length of object country;

L_0: the Expressway network length of reference country(Japan in his research);

A: Area of the country;

P: Population;

I: GDP per capita;

c: Unit Construction Cost.

Chiu's research(2011) has developed a methodology of macroscopic international comparison of the level of airport development with the consideration of the country's difference 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. In the Normalized Spatial Density Development Index model, the optimal number of airport in country is $n^* = \sqrt[3]{\frac{I^2 P^2 A}{9v^2 c^2 \pi}}$ (Where A: Area of the country; P: Population; I: GDP per capita; c: Unit Construction Cost; v: access speed). The normalized development index of airport number is

$$\gamma_{Air} = \frac{\frac{n_i}{n_0}}{\sqrt[3]{\frac{I_i^2 P_i^2 A_i}{c_i^2}} \Big/ \sqrt[3]{\frac{I_0^2 P_0^2 A_0}{c_0^2}}} \tag{29}$$

Where n_i: the number of airport of object country;

n_0: the number of airport of reference country(Japan in her research);

A: Area of the country;

P: Population;

I: GDP per capita;

c: Unit Construction Cost.

However, the above-mentioned development level index is based on the demand of all population in the country. In the case of multi-transport modes comparison, the demand of each transport mode should be separated. Therefore, mode share of each mode is considered as the factor to divide the demand in my study.

4.2 Mode share in Each Country

Mode share can be divided as two types: passenger mode share and freight mode share. Besides, passenger mode share contains passenger number mode share and passenger movement(passenger-km) mode share; freight mode share includes freight weight mode share and freight movement(ton-km) mode share. In the case of High-speed rail and air transport, there is rare freight movement, so the freight movement will not be considered as the factor of traffic demand in my comparison. According to the data availability and data conformity, passenger movement 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. The basic mode share information as shown as following.

Table 6 Information of passenger movement and passenger movement mode share

Country	ROAD (million passenger-km)	HSR (million passenger-km)	AIR（million passenger-km）	Mode share of ROAD	Mode share of HSR	Mode share of AIR
Belgium	131470	1061	7158	88.16%	0.71%	4.80%
France	773000	51864	152256	76.31%	5.12%	15.03%
Germany	949306	22561	205371	77.09%	1.83%	16.68%
Italy	97560	10746	39811	53.32%	5.87%	21.76%
Netherlands	158384.976	915	90184	60.00%	0.35%	34.16%
Spain	410192	11505	80134	79.92%	2.24%	15.61%

Country	ROAD (million passenger-km)	HSR (million passenger-km)	AIR（million passenger-km）	Mode share of ROAD	Mode share of HSR	Mode share of AIR
United Kingdom	736000	1014.00	230596	72.29%	0.10%	22.65%
China	1351144	92842.86	337520	54.56%	3.75%	13.63%
Japan	905907	76039	127859	70.37%	5.91%	9.93%
South Korea	100617	9937	82264	46.98%	4.64%	38.41%
USA	7874329	582.588	1227573	86.42%	0.01%	13.47%

4.3 Normalization of previous equation

Suppose the mode share of each mode is a_{Exp}, a_{HSR} and a_{Air}, the comparative accessibility development level index equations of each mode changes to

Expressway:

$$r_{Exp} = \frac{\frac{L_i}{L_o}}{\sqrt{\frac{a_{Expi} P_i A_i I_i^{1.5}}{c_i}} \Big/ \sqrt{\frac{a_{Exp0} P_o A_o I_o^{1.5}}{c_o}}} \tag{30}$$

High-speed rail:

$$r_{HSR} = \frac{\frac{L_i}{L_0}}{\frac{a_{HSRi} P_i^{0.295} A_i^{0.705} I_i^{0.295}}{c_i'^{0.295}} \Big/ \frac{a_{HSR0} P_0^{0.295} A_0^{0.705} I_0^{0.295}}{c_o'^{0.295}}} \tag{31}$$

Airport:

$$\gamma_{Air} = \frac{\frac{n_i}{n_0}}{\sqrt[3]{\frac{I_i^2 a_{Airi} P_i^2 A_i}{c_i^2}} \Big/ \sqrt[3]{\frac{I_0^2 a_{Air0} P_0^2 A_0}{c_0^2}}} \tag{32}$$

Where a_i: mode share of objective country;

a_0: mode share of reference country(Japan).

4.4 Result of the Integrated Model

Based on the above-mentioned equation, I made a 3-dimentional coordinate axis via SPSS to express the result the international multi-transport mode comparison. Each axis means the natural logarithm of the comparative accessibility development index of each transport mode. The result is shown in figure 22 and Table 7.

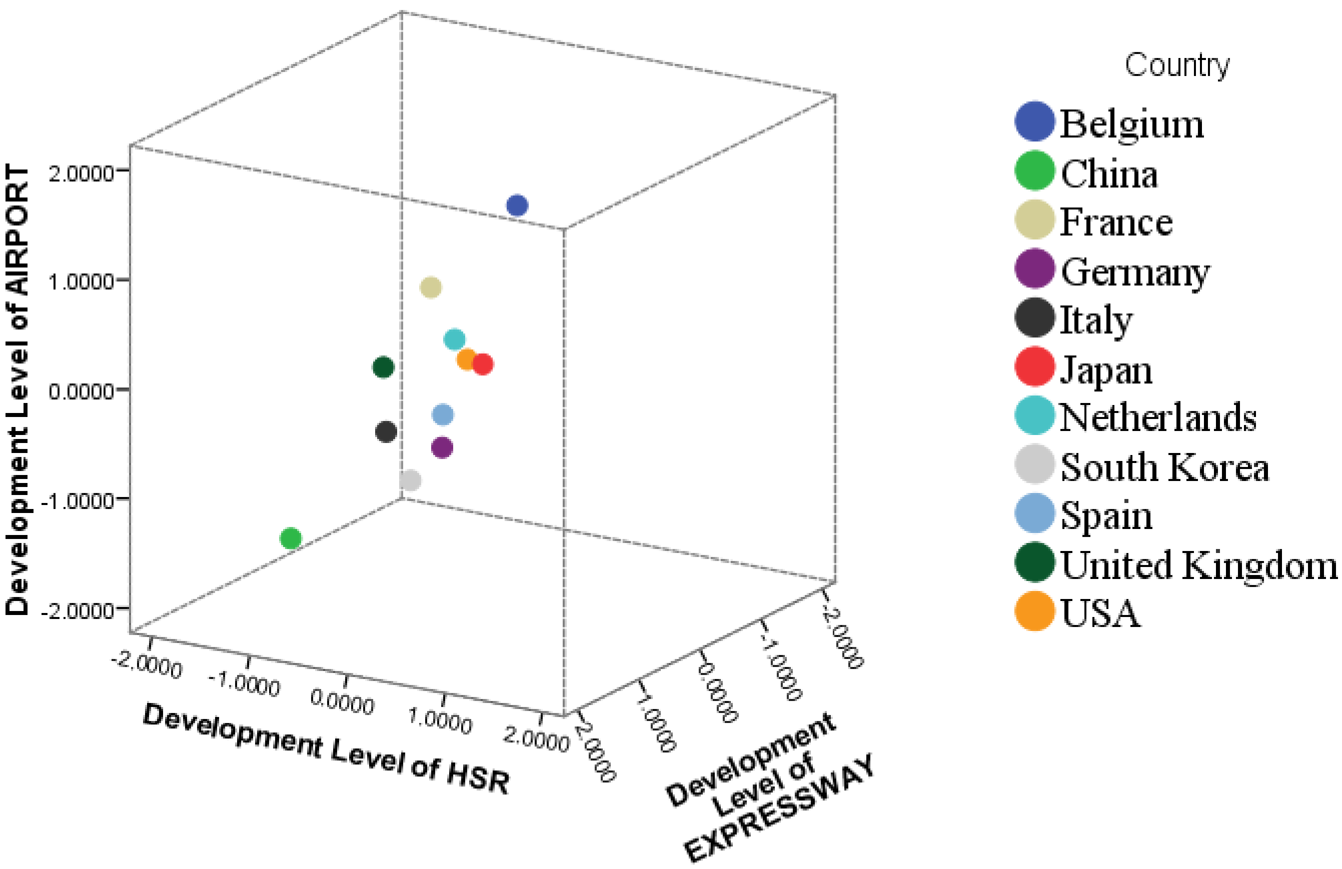

Figure 22 Result of multi-transport mode comparison

Table 7 Result of Integrated Model

Country	Development Level Index of HSR	Development Level Index of Expressway	Development Level Index of Airport
Belgium	1.371	1.567	4.667
France	0.672	0.899	1.762
Germany	0.768	1.288	0.479
Italy	0.441	1.476	0.524
Netherlands	0.745	2.139	1.266
Spain	0.989	1.493	0.678
United Kingdom	0.106	0.508	0.628
China	0.101	0.891	0.194
Japan	1.000	1.000	1.000
South Korea	0.659	1.629	0.359
Turkey	0.195	0.269	0.344
USA	0.029	0.882	0.956

Since the 3-dimentional figure is not so easily understandable, I want to focus on each surface. The detail results of integrated model and comparison with original models(Kondo's and Chiu's models) are shown as following.

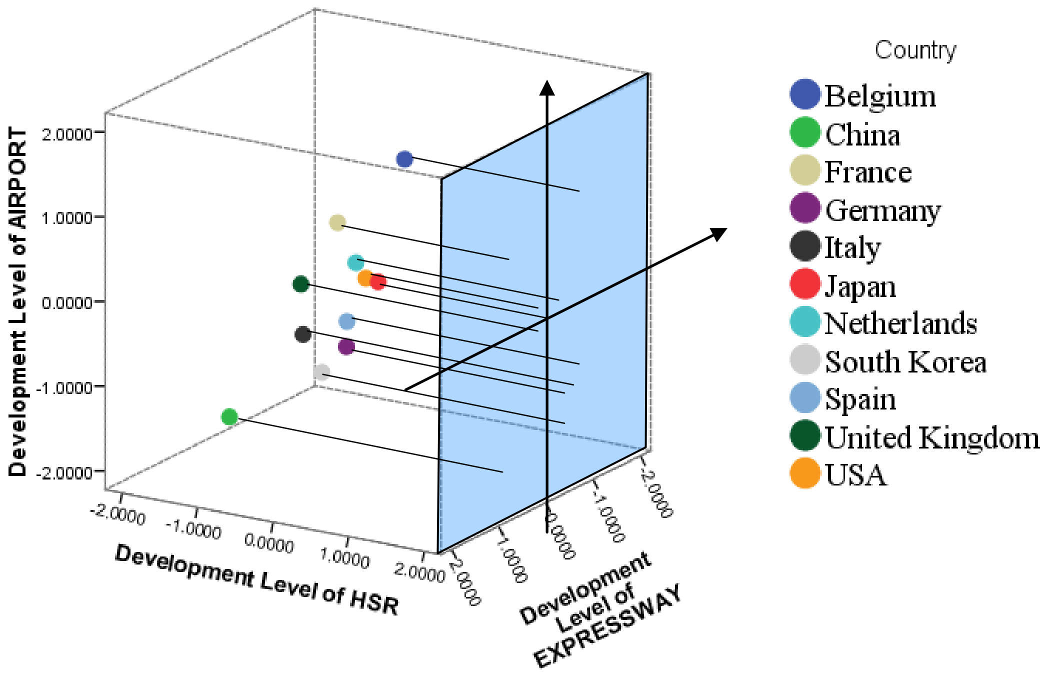

Figure 23 Surface of Expressway and Airport development level

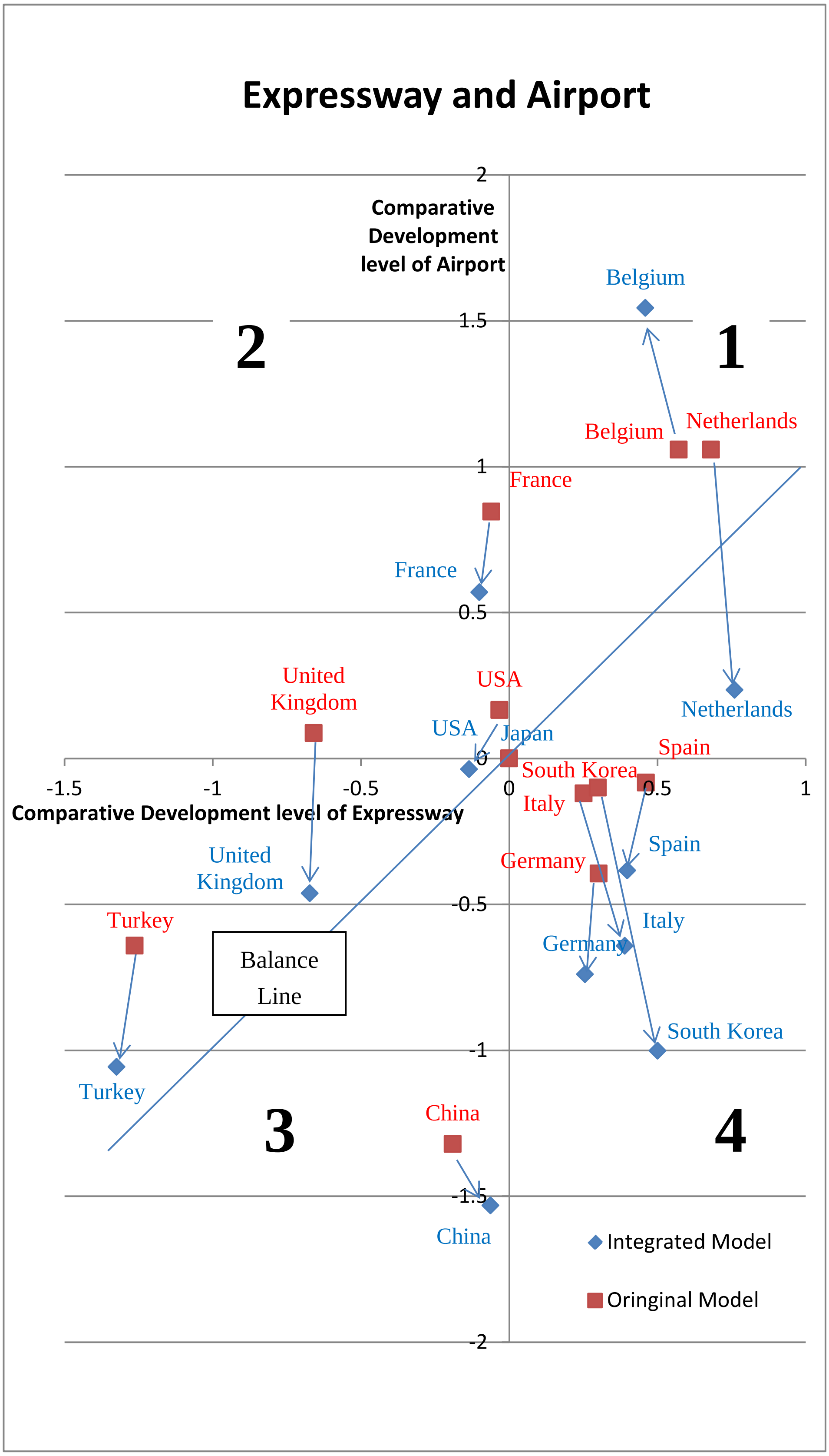

Figure 24 The comparative result of Expressway and Airport

The figure can be divided into four quadrants. The countries in quadrant 1 have higher level of both airport and expressway than Japan; The countries in quadrant 2 have higher level of airport and lower level of expressway compare to Japan; in quadrant 3, countries have lower level of both airport and expressway than Japan; in quadrant 4, all the countries have lower level of airport and higher level of expressway compare to Japan. According to the original model(Red points) and integrated model(Blue points), most countries move to the lower location except Belgium because compare with Japan, most countries' air mode share is higher, which means the comparative demand of air transport is higher than original model and it leads to the reduce of airport development level index. Because of this reason, USA and UK have higher development level of airport than Japan in original model but the in integrated model their level become lower than Japan. Belgium has highest development level of airport and Netherlands has highest development level of expressway in integrated model. The countries which move to the right position have lower mode share of road than Japan and the countries moving to the left position are opposite. Japan's development level of expressway is in the middle level and development level of airport is relatively high among all the countries. While the change of airport development level index is relatively large, the expressway development level index doesn't change so much since the mode share of road transport is not so different among all the countries. The 45° line in the figure is the balance line which means the same development level of Expressway and Airport. The countries under the line(Netherlands, Spain, Italy, South Korea, Germany, China) are the countries which have higher expressway level than airport compare to Japan's case, through this we can know that these countries focus more on expressway development than air transport development compare with Japan. The countries above the line (Belgium, France, USA, UK, Turkey) have higher development level of airport than expressway compare to Japan and which means these countries concentrate more on air transport than expressway.

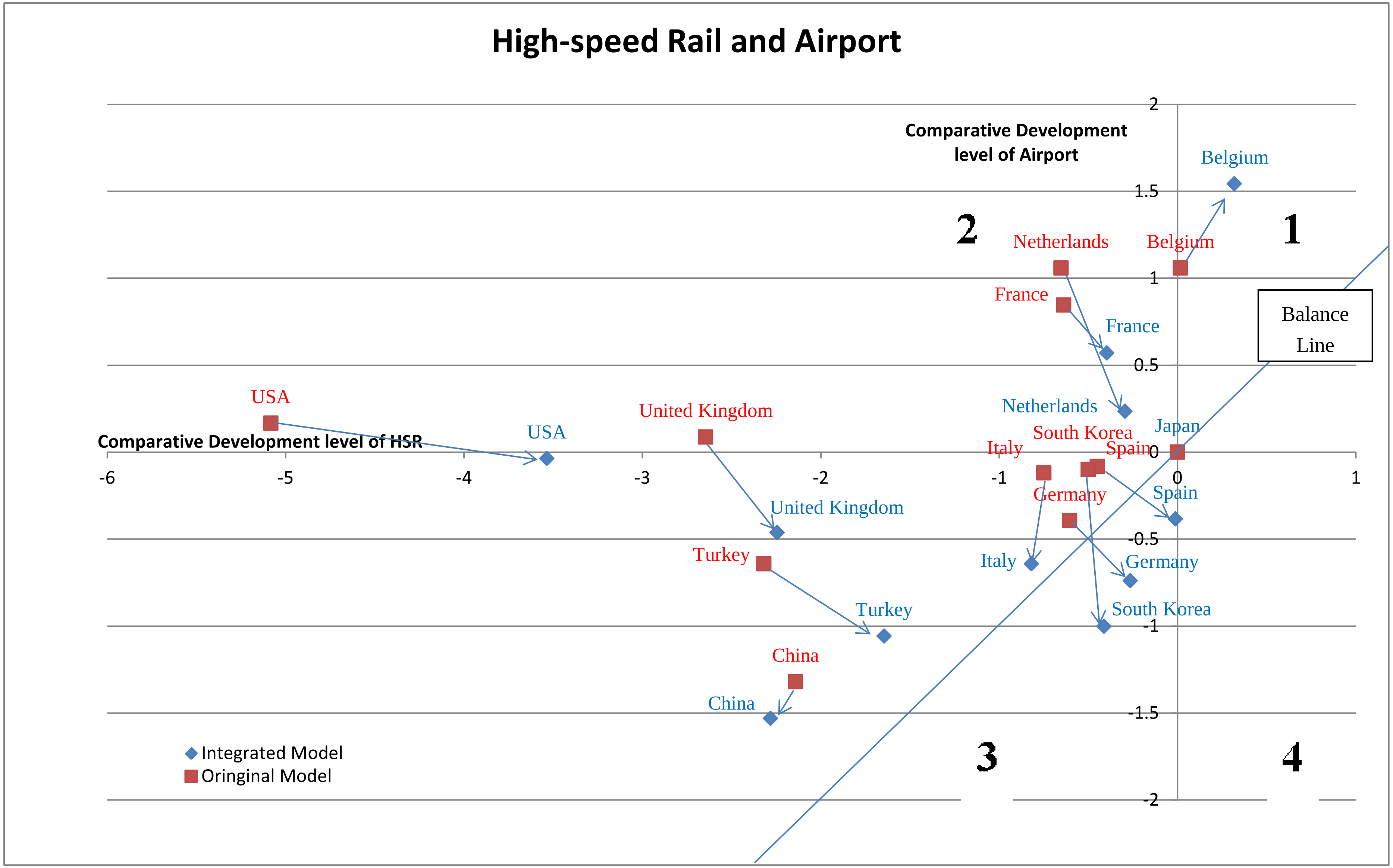

Figure 25 The comparative result of High-speed rail and Airport

From the result of High-speed rail and Airport, all the countries except China and Italy move to right which means their development level of High-speed rail is higher in the integrated model. It is because that only China and Italy have larger mode share of rail than Japan. The countries which move to the right position have lower mode share of rail than Japan and the countries moving to the low position have higher mode share of air compare to Japan. Consider the condition of airport level, most countries except China, Italy and Belgium move to right and lower position. Only Belgium has higher development level of High-speed rail than Japan in integrated model. In my opinion, the reason why Belgium has high level in all transport modes is that Belgium is located in the center 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. On the other hand, Belgium is a relatively small country and has limited population, which means the necessity level of transport infrastructure is not so large. Considering all these factors, Belgium should have quite high level of transport infrastructure. The development level of High-speed rail of USA increase dramatically since the rail mode share is very limited(0.1%) in USA. Compare to the change in Airport development, the change in High-speed rail is larger since the difference of rail mode share is more various. In original model, all the countries have higher development level of Airport than High-speed rail compare to Japan. But in the integrated model, South Korea, Germany and Spain have higher development level of High-speed rail than Airport compare to Japan's case. To South Korea, it is because that the mode share of air transport is very high(38.41%) which cause the big increase of comparative air transport demand and as the result, the development level of airport reduce dramatically. To Germany and Spain, the original development levels of High-speed rail and Airport are similar to Japan, while the rail mode shares of Germany and Spain are lower than Japan's and the air mode shares of Germany and Spain are higher than Japan's case, these reasons leads to the German and Spanish High-speed rail development levels are higher than airport in integrated model.

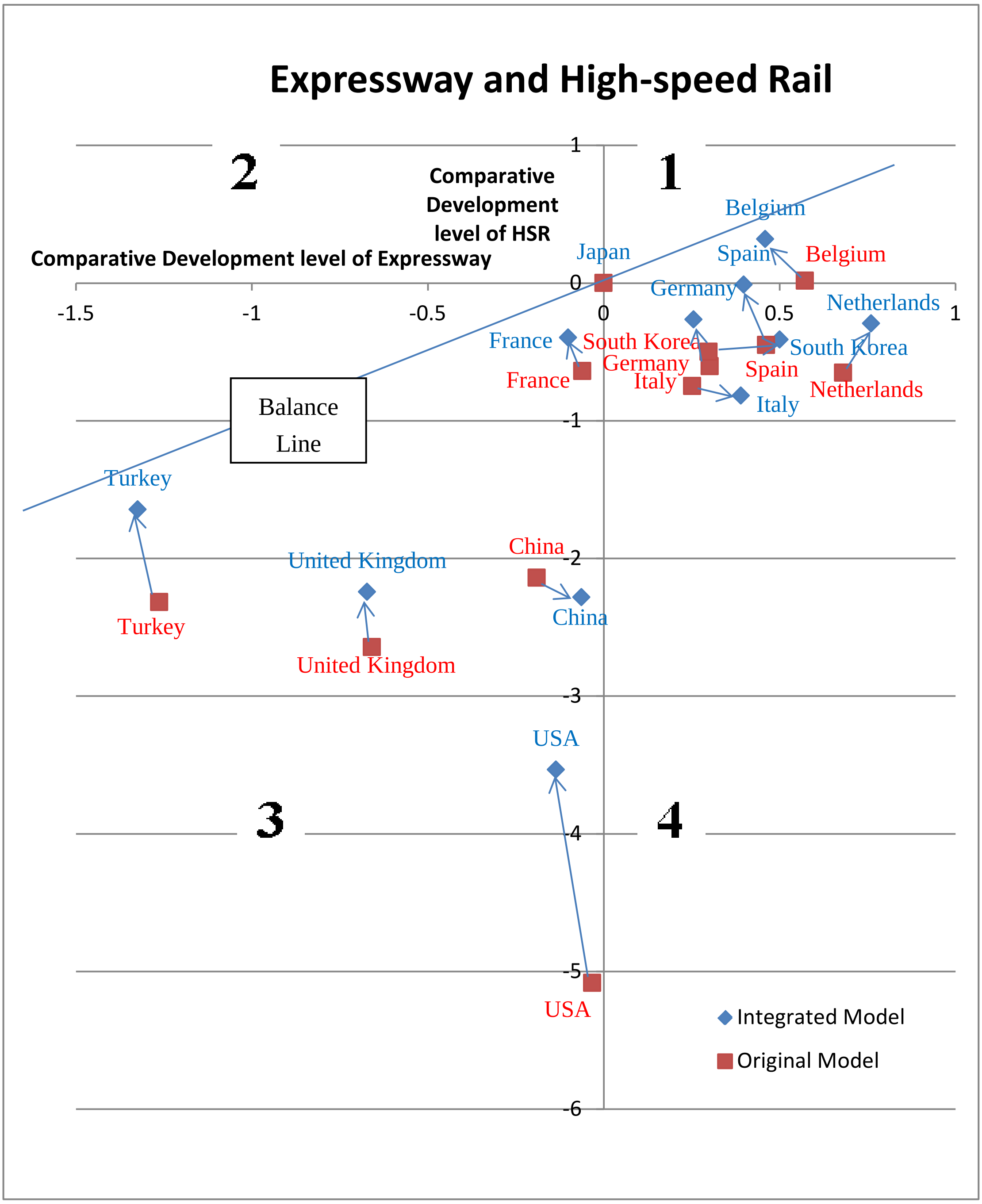

Figure 26 The comparative result of High-speed rail and Expressway

In the comparison of expressway and High-speed rail, all the countries in both original model and integrated model have higher development level of expressway than High-speed rail compare to Japan which means all the countries developed expressway more than High-speed rail compare to Japan. Other changes have been analyzed in former result.

4.5 Comparison of Land transport and Air Transport

While the result of each transport mode is very important, the comparison of land transport and air transport development level is also meaningful. Expressway and High-speed rail are two important factors of land transport and the development level of each mode is already derived previously. Therefore, I consider two kinds of way to derive the development level index of land transport.

1. Consider the High-speed rail and expressway has the same importance in land transport. The development level index of land transport is the product of the square root of High-speed rail index and expressway index.

$$Index_{land} = \sqrt{Index_{HSR} Index_{Exp}} \tag{33}$$

2. Consider the High-speed rail and expressway has the different importance in land transport. The importance parameter is the mode share of rail and road in land transport k_{rail} and k_{road}.

$$Index_{land} = Index_{HSR}^{\ k_{rail}} \times Index_{Exp}^{\ k_{road}} \tag{34}$$

The importance parameter of rail and road are shown in following table.

Table 8 Importance parameter of rail and road

Country	k_{road}	k_{rail}
Belgium	92.61%	7.39%
France	89.81%	10.19%
Germany	92.52%	7.48%
Italy	68.15%	31.85%
Netherlands	91.14%	8.86%
Spain	94.70%	5.30%
United Kingdom	93.46%	6.54%
China	63.17%	36.83%
Japan	78.13%	21.87%
South Korea	76.27%	23.73%
Turkey	97.53%	2.47%
USA	99.88%	0.12%

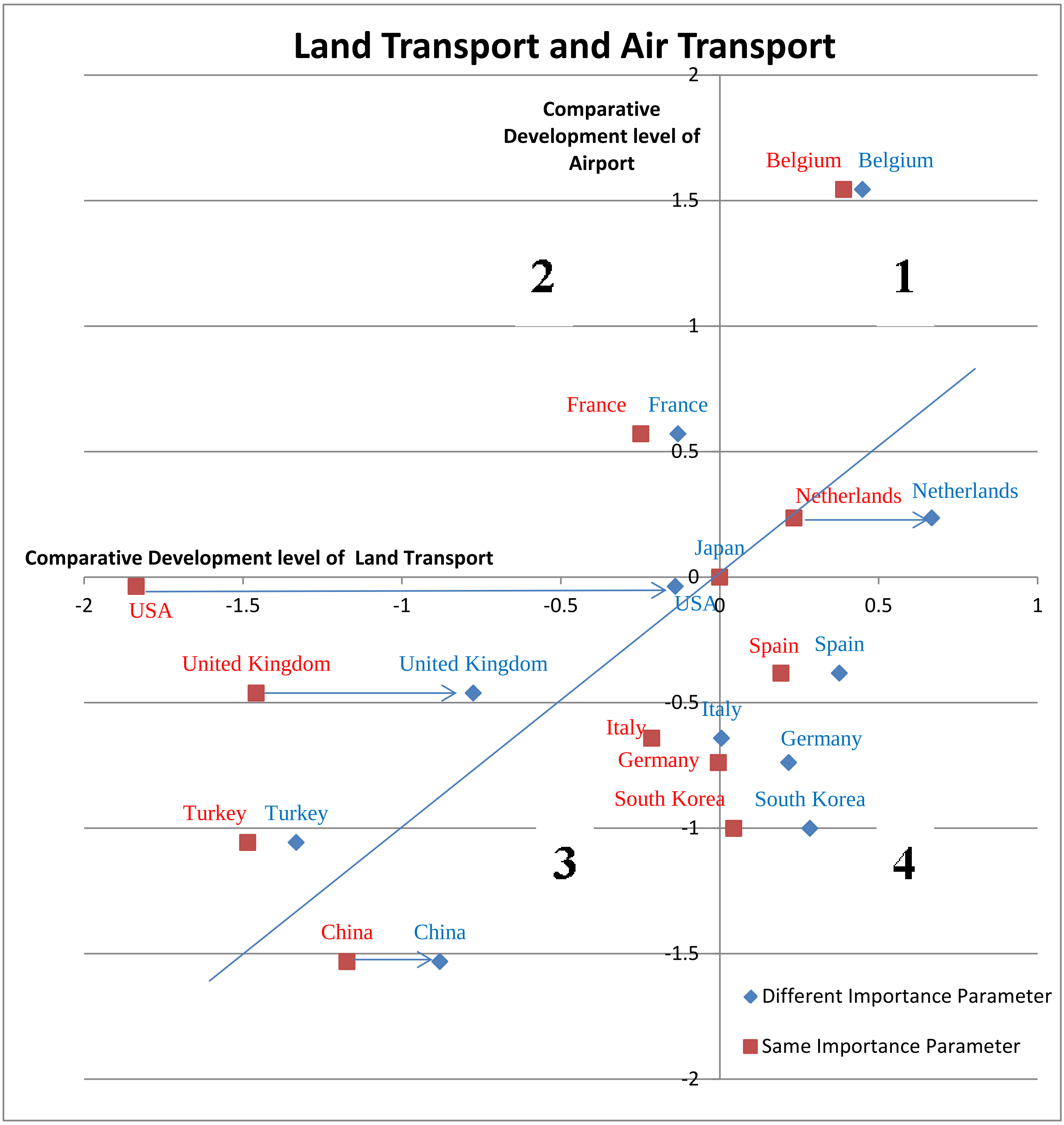

Figure 27 The result of land transport and air transport development level

In the result of same importance model, USA has the lowest level of land transport, which is even lower than turkey and China. This result is unreasonable compare to the common sense. In the result of different importance parameter, all the countries move to right which means their land transport development level increased. That is due to the reason that to all the countries, road transport is more important than rail transport and also their development level of expressway is higher than High-speed rail, so if we take the expressway and High-speed rail as the same importance, their development level of land transport will be lower than another model's result. Take USA as an example, its development level of land transport changed largely and it became acceptable compare to the last result. As the conclusion, the model of different importance parameter is more realistic than same importance model.

Chapter 5. Conclusions

1). This research developed a comparative model of international High-speed rail development level through the consideration of diverse geography, demography and economic condition. Basic theory is when total cost (time cost+construction cost) is minimal, the development level of High-speed rail is considered as optimal. The ratio of existing development level and optimal level is used as the development index. 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 coordinate axis. Based on the result of network length, all the countries can be divided into 3 groups. The first group: Taiwan, Belgium and Japan. The second group: Spain, South Korea, Germany, Netherlands, France and Italy. The third group: East China, Switzerland, Northeastern 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.

3). By applying the time series data, the development trend of High-speed rail in all countries is also achieved. 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. 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.

4). Japan’s regional data are applied in the model and the regional development level index tendency is derived. The result of length shows that all the regions which have High-speed rail in operation have higher development level than Japan’s total level in 2011. All the regions in Japan which have High-speed rail in operation have similar development level of speed, and the basic trend of development level is decreasing from 1965.

5). Due to the limitation of High-speed rail user, time cost of High-speed rail passenger is considered to substitute time cost of all population in the model. Compare with the 1st model, the comparative development level of length and speed in every country or area except Japan increased because the ratio of ridership/population of Japan is the highest among all the area. Especial USA and Turkey have more than 5 times development level of Speed than Japan in passenger model, which is unacceptable and unreasonable based on the reality because the necessity level of speed is not strongly related to the passenger number. In other words, passenger model is not suitable to apply to the comparison of development level of speed.

6). The combination of other transport mode is considered by applying the passenger movement mode share as the factor of traffic demand. The normalized development level index of each mode is expressed by 3-dimentional figure. The detail of each surface is analyzed. Belgium has high level in all transport infrastructures. Japan’s balance of expressway and airport is the middle level among all the countries. Only South Korea, Germany and Spain have higher development level of High-speed rail than Airport compare to Japan’s case. All the countries in integrated model have higher development level of expressway than High-speed rail which means all the countries developed expressway more than High-speed rail compare to Japan. Besides, the two kinds of model which can compare the development level of land transport with air transport are constructed. According to the result, the model of different importance parameter is more realistic.

Dedication

First of all, I would like to extend my sincere gratitude to my supervisor, Professor IEDA Hitoshi, for his constant encouragement and guidance. He has walked me through all the stages of the master course. Without his consistent and illuminating instruction, the master research could not have reached its present form. In particular, before each presentation of department or conference, Professor IEDA always spends a lot of time on helping me to prepare the abstract and slides. In the preparation of the thesis, he has spent much time reading through each draft and provided me with inspiring advice. Without his patient instruction, insightful criticism and expert guidance, the completion of this thesis would not have been possible.

I am also deeply indebted to members of TRIP Lab for their direct and indirect help to me. Thankfulness goes to Senior Lecturer Kiichiro HATOYAMA, Assistant Professor Norihisa SHIMNA and Naesun PARK, whose profound knowledge of transport system helped me a lot on the process of research and problem finding. Students in our lab offered me support not only on the research but also on the daily life. I enjoyed the different culture performed by everyone. Thanks to the Team Himawari and Team Wasabi members, for the support in the student meeting during this two years. Also, thankfulness goes to Secretary KUKITA, who helps us a lot on the procedures such as making appointment with professor.

Last my thanks would go to my beloved family, especially my girlfriend Hanhan, for their loving considerations and great confidence in me all through these years. We are looking forward to a wonderful future.

Appendix

Table 9 Construction Cost and Condition of each line in SPSS regression

Country	Line	Open Year	Length（km)	Operating Speed (km/h)	Total const. cost($ billion)	Unit cost($ million/km)
Belgium	HSL 1	1997	72	300	1.94966	27.08
Belgium	HSL 3	2007	36	260	1.13959	31.66
France	LGV Méditerranée	2001	250	300	5.2174	20.87
France	LGV Est	2007	300	300	5.492	18.31
France	LGV Perpignan–Figueres	2010	44.4	300	1.5103	34.02
France	LGV Sud Europe Atlantique	2016	302	300	9.8856	32.73
Germany	Hanover–Würzburg high-speed railway	1991	327	250	9.18537	28.09
Germany	Nuremberg–Munich high-speed railway	2006	171	300	4.9428	28.91
Germany	Frankfurt–Mannheim high-speed railway	2011	85	300	2.746	32.31
Germany	Nuremberg–Erfurt high-speed railway	2016	190	300	7.0023	36.85
Italy	Turin–Milan high-speed railway	2006-2009	125	300	3.54234	28.34
Italy	Milan–Bologna high-speed railway	2008	214.7	300	9.4737	44.13
Italy	Bologna–Florence high-speed railway	2009	78.5	300	7.1396	90.95
Netherlands	HSL ZUID	2009	125	300	9.1991	73.59
Spain	Madrid-Valencia high-speed railway line	2010	438	300	9.0618	20.69
Spain	Madrid-Levante high speed-railway line	2015	940	300	17.1625	18.26
United Kingdom	High Speed 1	2007	113	300	9.1582	81.05
China	Qinshen PDL	2003	404	250	2.45548	6.08

Country	Line	Open Year	Length (km)	Operating Speed (km/h)	Total const. cost($ billion)	Unit cost($ million/km)
China	Hening PDL	2008	166	250	3.91	23.55
China	Jiaoji PDL	2008	364	250	1.7204	4.72
China	Hewu PDL	2008	351	250	2.62752	7.49
China	Jingjin ICL	2008	115	350	3.3626	29.24
China	Shitai PDL	2009	190	250	2.67053	14.06
China	Yongtaiwen PFL	2009	268	250	2.546192	9.50
China	Wuguang PDL	2009	968	350	18.23624	18.77
China	Wenfu PFL	2009	298	250	2.8152	9.45
China	Fuxia PFL	2010	275	250	2.386508	8.68
China	Chengguan PDL	2010	65	250	2.08012	32.00
China	Changji ICL	2010	111	200	1.50144	13.53
China	Zhengxi PDL	2010	455	350	5.522484	12.14
China	Huning HSR	2010	301	300	7.82	25.98
China	Huhang PDL	2010	150	300	4.580956	30.54
China	Hainan ER ICL	2011	308	200	3.15928	10.26
China	Jinghu HSR	2011	1318	350	34.54876	26.21
Taiwan-China	Taipei–Kaohsiung	2007	345	300	16.24428	47.08
Japan	Morioka–Hachinohe (Tohoku)	2002	97	260	6.11	62.99
Japan	Shin-yatsushiro and Kagoshima-chuo(KYUSHU SHINKANSEN)	2004	127	260	8.32	65.51
Japan	Hachinohe–Shin Aomori (Tohoku)	2010	82	300	6.2582	76.32
Japan	Hakata – Shin Yatsuhiro (Kyushu)	2011	130	260	10.53	81.00
South Korea	Seoul – Daegu	2004	330	300	11.83	35.86
South Korea	Daegu – Pusan	2010	82	300	4.56	55.58
Turkey	Ankara-Konya	2011	212	250	0.5647	2.66
Turkey	Ankara-Istanbul line	2011	533	250	1.27	2.38

Table 10 The development level index of Length r_L of each year

Country	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Belgium	0.000	0.000	0.000	0.000	0.365	0.365	0.690	0.682	0.676	0.674	0.672	0.666	0.663	1.015	1.016	1.012
France	0.000	0.128	0.207	0.337	0.371	0.445	0.443	0.438	0.434	0.433	0.432	0.521	0.518	0.521	0.528	0.527
Germany	0.000	0.000	0.040	0.193	0.280	0.280	0.365	0.379	0.515	0.497	0.551	0.547	0.544	0.547	0.547	0.547
Italy	0.000	0.126	0.119	0.132	0.132	0.132	0.131	0.129	0.128	0.128	0.289	0.287	0.379	0.472	0.473	0.473
Netherlands	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.520	0.521	0.520
Spain	0.000	0.000	0.000	0.154	0.154	0.154	0.152	0.341	0.338	0.343	0.397	0.468	0.492	0.496	0.638	0.639
Switzerland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.128	0.127	0.127	0.127	0.126
United Kingdom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.047	0.046	0.046	0.070	0.070	0.071	0.071	0.071
China	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.008	0.008	0.027	0.059	0.086	0.117
Taiwan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.382	1.380	1.385	1.382	1.386
Japan	0.440	0.735	0.701	0.723	0.845	0.851	0.891	0.887	0.931	0.931	0.933	0.933	0.927	0.925	0.951	1.000
South Korea	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.496	0.491	0.488	0.485	0.488	0.491	0.606	0.603
Turkey	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.098	0.099
USA	0.000	0.000	0.000	0.000	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Russia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.007	0.007
East China	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.017	0.017	0.017	0.017	0.058	0.127	0.185	0.256
Northeastern USA	0.000	0.000	0.000	0.000	0.124	0.124	0.124	0.123	0.123	0.123	0.122	0.122	0.122	0.122	0.121	0.122

Table 11 The development level index of Speed r_V of each year

Country	1980	1985	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Belgium	0.000	0.000	0.000	0.000	1.308	1.308	1.302	1.285	1.274	1.271	1.267	1.256	1.249	1.226	1.226	1.222
France	0.000	1.427	1.359	1.339	1.353	1.365	1.359	1.342	1.331	1.328	1.324	1.326	1.319	1.325	1.327	1.325
Germany	0.000	0.000	1.229	1.200	1.182	1.182	1.208	1.190	1.131	1.130	1.139	1.130	1.124	1.130	1.130	1.126
Italy	0.000	1.181	1.115	1.112	1.114	1.111	1.105	1.092	1.083	1.081	1.198	1.189	1.204	1.215	1.217	1.217
Netherlands	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.248	1.250	1.249
Spain	0.000	0.000	0.000	1.250	1.253	1.249	1.241	1.263	1.251	1.241	1.246	1.248	1.245	1.252	1.273	1.274
Switzerland	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.041	1.033	1.034	1.030	1.020
United Kingdom	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.310	1.297	1.295	1.290	1.279	1.284	1.299	1.297	1.295
China	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.337	1.325	1.312	1.296	1.277	1.172	1.350	1.407	1.394
Taiwan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.236	1.235	1.240	1.231	1.234
Japan	1.204	1.170	1.116	1.050	1.010	1.018	1.021	1.016	1.011	1.012	1.014	1.014	1.007	1.005	1.000	1.000
South Korea	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.241	1.229	1.221	1.214	1.223	1.231	1.217	1.211
Turkey	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.218	1.205	1.215
USA	0.000	0.000	0.000	0.000	1.093	1.091	1.089	1.086	1.082	1.079	1.075	1.072	1.071	1.072	1.070	1.071
Russia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.264	1.249	1.238
East China	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.263	1.251	1.240	1.229	1.214	1.121	1.293	1.351	1.358
Northeastern USA	0.000	0.000	0.000	0.000	1.053	1.050	1.048	1.046	1.043	1.039	1.036	1.033	1.032	1.032	1.029	1.032

Table 12 The Operation Length(km) of High-speed rail in Japanese regions

Region	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2011
北海道	0	0	0	0	0	0	0	0	0	0	0
東北	0	0	0	0	344	344	431	620	717	799	799
関東	77	77	77	77	348	348	348	367	367	367	367
中部	290	290	290	290	441	441	441	540	540	540	540
近畿	148	148	254	254	254	254	254	254	254	254	254
中国	0	0	371	371	371	371	371	371	371	371	371
四国	0	0	0	0	0	0	0	0	0	0	0
九州	0	0	77	77	77	77	77	77	204	204	334

Table 13 The development level index of Speed r_L of Japanese regions

Region	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2011
北海道	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
東北	0.00	0.00	0.00	0.00	0.78	0.77	0.96	1.37	1.58	1.77	1.77
関東	0.35	0.34	0.34	0.33	1.49	1.47	1.47	1.54	1.53	1.54	1.54
中部	0.64	0.62	0.61	0.60	0.90	0.89	0.88	1.08	1.07	1.07	1.07
近畿	0.78	0.76	1.29	1.28	1.27	1.25	1.24	1.24	1.24	1.25	1.25
中国	0.00	0.00	1.64	1.62	1.61	1.59	1.58	1.58	1.57	1.58	1.58
四国	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
九州	0.00	0.00	0.28	0.27	0.27	0.27	0.27	0.26	0.70	0.70	1.15

Table 14 The Average Speed(km/h) of High-speed rail in Japanese regions

Region	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2011
北海道	0	0	0	0	0	0	0	0	0	0	0
東北	0	0	0	0	300	300	266	224	229	232	232
関東	270	270	270	270	273	273	273	272	272	272	272
中部	270	270	270	270	260	260	260	260	260	260	260
近畿	270	270	270	270	270	270	270	270	270	270	270
中国	0	270	293	293	293	293	293	293	293	293	293
四国	0	0	0	0	0	0	0	0	0	0	0
九州	0	0	300	300	300	300	300	300	275	275	269

Table 15 The development level index of Speed r_V of Japanese regions

Region	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2011
北海道	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
東北	0.00	0.00	0.00	0.00	1.24	1.22	1.07	0.90	0.92	0.94	0.94
関東	1.13	1.10	1.09	1.07	1.07	1.05	1.05	1.05	1.04	1.05	1.05
中部	1.11	1.08	1.06	1.05	1.00	0.98	0.98	0.97	0.97	0.97	0.97
近畿	1.10	1.06	1.06	1.05	1.04	1.02	1.02	1.02	1.01	1.02	1.02
中国	0.00	1.09	1.17	1.16	1.15	1.14	1.13	1.13	1.12	1.13	1.13
四国	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
九州	0.00	0.00	1.21	1.20	1.19	1.18	1.17	1.17	1.07	1.07	1.05

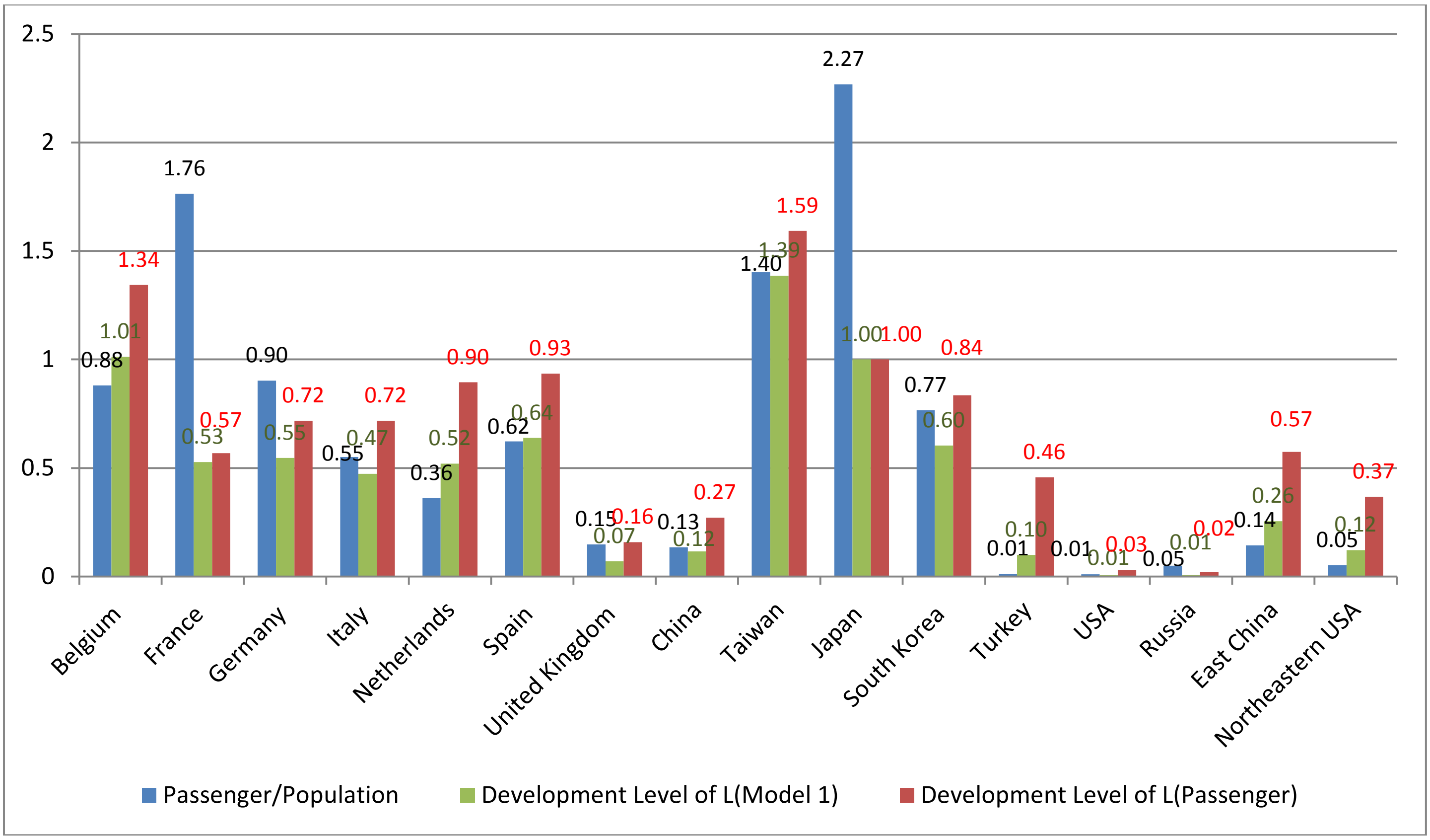

Figure 28 Result of r_L in Passenger Model

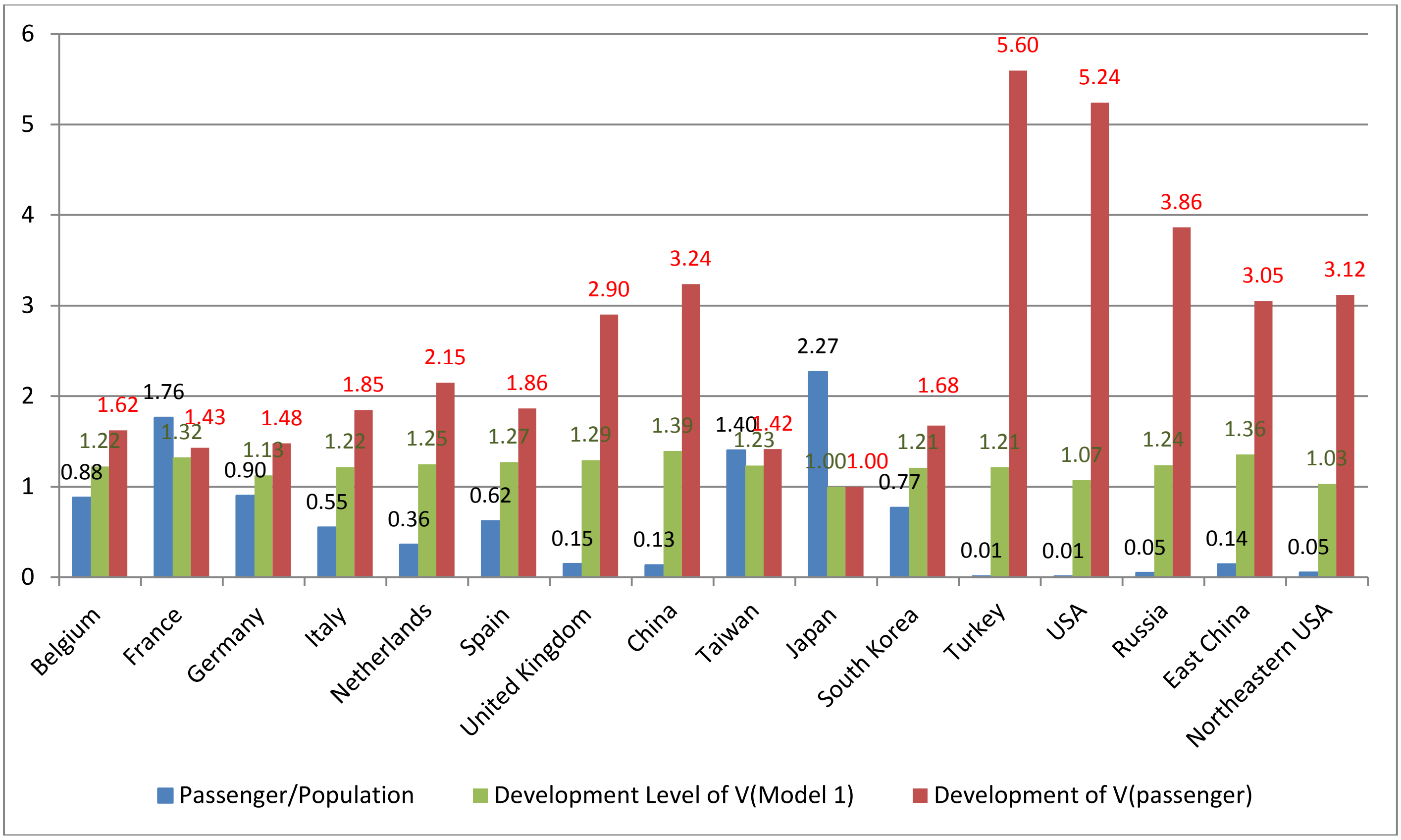

Figure 29 Result of r_V in Passenger Model

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