博　士　論　文

International Comparison of the Development Level of Inter-regional Transport Infrastructure: Methodology Development and Policy Analysis

（幹線交通インフラの開発レベルの国際比較研究：
評価手法の開発と政策分析）

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Abstract:

Inter-regional transport infrastructure is vital for national and regional development. Huge investments are needed in the coming decade in order to cope with the growing demand and deal with issues of maintaining the current existing stock around the world. Assessing current development status, reviewing development history and evaluating the effectiveness of the policy and investment on inter-regional transportation infrastructure will ultimately help the discussion of long-term development strategy.

The objectives of this research are: 1) Develop the practical methodology to assess and compare the development level of inter-regional transport infrastructure (expressway, high-speed railway, airport and all modes). The comparison method should capture the geographic, demographic and economic differences. 2) More importantly, apply the methodology to conduct development level comparisons, policy analysis and draw policy implications.

In the first stage of this research I further develop the practical methodology of Normalized Development Level (NDL) to assess the development level of inter-regional transport infrastructure including expressway, high-speed railway and airport. It is not only able to measure the development level of inter-regional transport infrastructure but also comparable of capturing the historical change of each system among different countries (domestic regions and international regions), and most importantly the patterns towards different modes. It is the first time that the development level comparison is measured with consideration of economic, demographic and geographic difference as well as the attributes of different transport modes. In the second stage, I apply the method to conduct development level comparisons and policy analysis on 20 countries across the globe from 1960s to 2014. Implications have been drawn for policy-makers in central, local governments as well as international organizations.

I: The main contributions in the methodology part:

Overall, two indices, namely Normalized Development Level Index on Spatial Accessibility, Normalized Development Level Index on Resources Quantity, are further developed to assess the development level of inter-regional transport infrastructure on spatial accessibility and capacity (resources quantity). An integrated assessment approach on multi-modes infrastructure is achieved, which fills the blank research area. The improvements have been made in the NDL indices are described as follows: 1) further enrich development level comparison concept through articulating the definitions, essentially the method of which compares the supply and necessity of inter-regional transport infrastructure with other country; 2) improve the theoretical formation of necessity and justify the assumptions and simplifications of model components, which enables the comparisons based on theoretical sound and cost-effective method ; 3) unify the model construction of each transport modes, which enables the integrated assessment on all modes later on; 4) add the high-speed rail Normalized Development Level Index on Spatial Accessibility; 5) enable application at different scales by solving the passing demand issues caused by international traffic which applies gravity model and use trans-country OD data set to estimate the international passing demand; 6) Most importantly, with the above improvements, the method is able to make integrated assessment on all modes. It fills the blank research area of integrated assessment on all modes. Development patterns on different kinds of modes can be identified.

II: The main findings in comparison results and policy analysis are described as follows:

Comparison results of the development level

Comparison results of the development level of expressway, high-speed railway, airport on around 20 countries during 1960s to 2014, are presented in this thesis. It displays the development level changes and enables policy-makers to track the development level of each modes and all modes in the history as well as assess current development status. In detail, the application of the method widely expands to more countries and scales for 1) country level comparisons: conducted development level comparisons of 15 countries for expressway, high-speed railway, airport and integrated all modes; 2) domestic region level comparisons: conducts detailed comparisons on 2 countries at regional level, namely Japan and China, for expressway, high-speed railway, airport and integrated all modes; 3) international region level comparisons: conducted assessment on the EU for expressway development; 4) airport Infrastructure: conducts detailed international comparison on airport infrastructure. The regional development pattern reveals the effectiveness of this

method.

1) Country level comparisons:

Expressway: (1) General trends: the Netherlands has the highest development level in this international comparisons. The EU countries generally slowed down its development pace after 1975s. The development level of Spain has a sharp increase after joining the EU in 1986. China and Korea are observed to have the highest development pace among the selected countries. (2) Regarding the Netherlands, the rationale of the comparatively high level of development, is partially because of its transport and logistic sector has been playing key role in its economy as the direct contributor, while transport infrastructure built by most of other countries are mainly for the indirect contribution to economy growth. Similar approach can be observed in Singapore's port and airport development. (3) In the EU, the trend of slowing down the development after 1975s can be interpreted as the reflections on the oil dependency. As the oil crisis occurred in the mid-1970s, the Netherlands revised its expressway development master plans into various versions with lower density comparing with the version before the oil crisis. Other EU countries also share similar development pace, which is slowed down after 1975s. Another reason is many countries in the EU started to shift the focus of regional development to metropolitan development after 1980s. (4) Spain enjoyed a sharp increase in the development level after joining the EU in 1986. It catches up with the EU 12 countries' benchmark level in 2005. It has benefited from the EU funding and policy on improving the connectivity in the EU. (5) The highest (or exceptional) growth rate have been observed in China and Korea. It is partially due to the acceleration of investment on infrastructure in response to the Asia financial crisis in 1997 and globe financial crisis in 2008.

High-Speed Railway: General trends: Japan maintained the highest development level until 2010. Korea surpassed Japan in 2010 and several countries are approaching the same development level as Japan. After 2000, the countries newly adopted the high-speed railway technology increased their development level sharply, which shapes a new dynamic in the high-speed railway development in terms of technology development as well as expansion of projects.

Airport: China's airport development level decreased sharply comparing with other countries. Take its aggressive development in expressway and high-speed railway into consideration, China has been taking a different approach in airport development.

Integrated Assessment on all modes (1) In general, this research integrates the NDL for expressway, high-speed railway and airport, using the triangle to represent the mode pattern and the integrated development level suggested by the size of the triangle. Each mode at the certain year is compared with the base line year of national NDL 1 of Japan. The shape of the triangle indicates national "mode choice" or development outcomes. (2) Several countries are more expressway oriented development, namely Italy, Belgium and the Netherlands. Another group is the countries which have relatively higher level in airport than other modes, including the UK, France, Germany, Norway and the US. Norway is more relied on the airport infrastructure in the inter-reginal development. One more interesting pattern is that Korea and China both developed towards expressway and high-speed railway. It might indicate these countries have made wise decision toward the energy efficient mode. In terms of the overall integrated development level, Japan, Germany, Korea, the US and Belgium have the highest level. Lower density countries have the pattern more towards airport development with only one exception, China.

2) Domestic region level comparisons:

Japan Airport: (1) The airport development in Japanese regions has following patterns: a) initial development level is high; b) the disparity between regions becomes gradually larger; c) the level of advanced regions are the lowest; d) regions located in the edge of the country have higher development level. (2) A gap between infrastructure provision and operation has been identified in Japan's civil aviation development. (3) The policy, which intended to focus the development in metropolitan airports, is not effective in the past twenty years.

Japan Expressway: The disparity between regions becomes smaller and smaller. It demonstrates the effectiveness of Japanese policy on regional balance development

Japan High-speed Railway: The development of high-speed railway started from the advanced regions, namely Kanto and Kansai as well as Kinki. Later other regions caught up with the advanced region. The Chugoku region have a high development level, partly because of its location, which plays the role of connecting west and east. Similar trend has been observed in China as well.

Japan Integrated All Modes: The regions located in the edge of the country have higher airport development level than other modes. It might reveal the investment decision (or the outcome of the investment) of inter-regional transport infrastructure are more toward air transport. Secondly, compared to high-speed railway, NDL within these regions, expressway NDL has higher value. The regions located in the middle of the country have higher high-speed railway development level than other modes. The regions in the middle as well as the advanced regions are taking a more balanced approach in each mode of development as the NDL value are similar in each mode. The size of the triangle reveals the integrated NDL. The advanced regions in Japan do not have the highest NDL. It helps the policy-maker to make decision on specific mode with the consideration of other modes, in a coordinated manner.

3) International region level comparisons: Expressway Development of the EU

The results reveal the expressway development trend of the EU 12 and the EU28, which can assist the EU and other region to set the benchmark for its expressway development.

4) International Comparison on Airport Infrastructure Development

The metropolitan regions in Japan locate in the lowest bound of the development level across the entire country. In order to draw insights from international comparison, we have conducted the detailed regional comparison for another three large economy in the World, namely the UK, France and Germany. The findings are the metropolitan regions in all the other three countries have comparably high development level. It further reveals the issue that Japan should focus on the improvements of its airport development in its metropolitan regions.

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Chapter 1 Introduction and Review

Inter-regional transportation infrastructure is vital for national and regional development. The demands for transport infrastructure are still rising. Assessing current development status, reviewing development history and evaluating the effectiveness of the policy and investment on inter-regional transportation infrastructure will ultimately help the discussion of long-term development strategy. The purpose of this research is to i) further develop a practical methodology to compare the development level of inter-regional transport infrastructure (including expressway, high-speed rail, rail and airport) across countries (regions) and time, which is missing from current development level comparisons. ii) More importantly, I apply this methodology to analyze the development of inter-regional transport infrastructure across the globe and draw associated policy implications.

In Chapter I, I introduce the background of this research and limitations on existing practices in Section 1.1. Section 1.2 highlights the targeted audience of this research, and how this research are going to serve different audience for various purposes. Section 1.3 contains the framework of this research.

In Chapter 2 and 3, I explain the construction of the framework of Normalized Development Level for international comparison. The focuses are i) shaping a definition of development level for inter-regional transport infrastructure; ii) formulate the details for all modes of transport. Chapter 4 is methodology improvements in order to apply the NDL to other scales. Chapter 5 is the application of the method at country level for all modes of transport, followed by policy discussion. In Chapter 6, the development level of each regions within a country is examined and discussed, focusing on Japan and China. In Chapter 7, the NDL is applied to global region. Preliminary analysis is carried out for EU. Chapter 8 concludes the contributions and findings of this research as well as future works.

1.1 Background and Problem statement

1.1.1 Huge investment gap for inter-regional transport infrastructure

Inter-regional transport infrastructure is vital for national and regional development. It also plays important role in national integration. In current globalized world, the inter-regional transportation plays more and more important role in facilitating the movements across larger geographic area.

The demands for transport infrastructure are still rising. Not only huge investment is needed to meet the demand, there is a significant investment gap. Based on a comprehensive review of recent global estimates on infrastructure demands done by World Bank Group, the annual global infrastructure investment amount would be around 836 billion US dollars in developing countries (around 6 percent of current GDP per year over the period 2014 to 2020 in developing counties) as the lower bound estimates. Transport accounts for around 30% of the total investments. (Inderst and Stewart 2014).According to the estimation, developed countries will require about 285 billion annual infrastructure investments to cope with growing demand and deal with issues of maintaining the current existing stock.

In a larger scope, there are also emerging needs for regional infrastructure to facilitate the regional cooperation. For example, the needs rising from improving Asia’s trade competiveness through better infrastructure connections (ADB.ADBI 2009).

Therefore, methods, tools and models, which could support the investment planning at various scales, are badly needed. The limitations of existing tools and data will be discussed in section 1.3.

1.1.2 What is the level of development of inter-regional transport infrastructure?

In this section, we move to the discussion of a critical question: What is “the level of development of inter-regional transport infrastructure?”

In development study, there have been a lot of debate on a critical question: “What is development level”(Soubbotina 2004). The World Bank Report *Beyond Economic Growth* discussed the word of development is far beyond the goal of economic growth, but also include environmental sustainability, equity, health improvement etc. Therefore, different measurements have been developed to track the achievement of these development goals, as well as compare the level. There are also limitations of different measurements. Take indicators which evaluate the economic development for example, GDP, GDP per capita and purchasing power parity conversion factor are developed to address those limitations respectively.

Similarly, what is the level of development of inter-regional transport infrastructure achieved by different countries? Assessment methods of the development level of inter-regional transport infrastructure are needed for planning, setting policies and investment strategies. However, it is a difficult question in several ways. Firstly, what is the definition of development in inter-regional transport infrastructure? Associated with this question is that what is the development supposed to achieve. Secondly, how to measure it, more specifically how to measure the achievement for the specific goal or set of goals. Thirdly, we need to mind that there is a cost of model construction, data collection and data availability. Fourthly as we will further use the level of development measurement for assessment and judge the relative progress in a country as well as across countries. How we make sure the targeted users understand the meaning of the index. This research is trying to answer this difficult question.

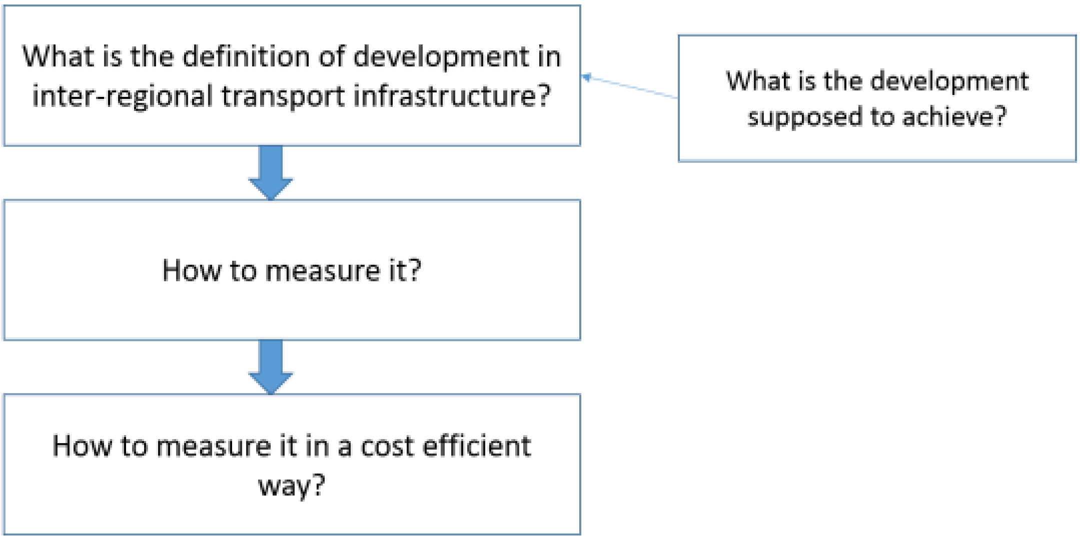


Figure 1 What is the level of development of inter-regional transport infrastructure?

1.1.3 Comparison is a fundamental tool for analysis

The core of this research is comparing the development level with other countries and regions in order to assist the decisions. In this section, I will discuss why comparison is a fundamental tool for analysis.

Comparison is a fundamental tool for analysis in political science(Collier 1993). Comparing with other countries are commonly used in the development world. The World Bank report *Beyond Economic Growth* highlights the importance of comparing the development data with others: It can help the country to understand the status, prospects and priorities through learning the difference and similarities. For example, the economist use GDP to measure the economic development of a country and enable the comparison across countries. Various indicators have been developed to measure, compare and monitor the country's social and economic development. In one hand, as every country faces a lot of choices with uncertainty, learn from other country's development history and experience might be the best way to minimize the uncertainty.(Soubbotina 2004)

The global governance institutions, multilateral banks and international organizations, such as World Bank, OECD conducted extensive global comparisons to understand the trend, find the best practices and experience, identity the needs and provide the solutions accordingly. The efforts of these multilateral banks on global comparisons can be demonstrated through its world development indictors programs (The World Bank 2015)

On the other hand, in this globalization world, the country's decision (or region's decision) is also influenced by others in order to win competition and meet the expectation from its citizen. Take airport and port development for example, the competition for international hub and regional hub also induced the competition for infrastructure upgrade.

Similarly, it is very meaningful to compare the development level of inter-regional transport infrastructure across countries and time to draw useful development insights. In the national level assessment and planning, comparing the development level is the common practices for international agencies, national level governments, state level governments and investors. No matter developed country or developing country, the first chapters of planning documents will normally conduct some international comparisons. Take Japan for example, the Japanese Ministry of Transport used the simple statistic indicators to compare with other countries' status in their expressway master plan (see Figure 2). Take United Kingdom for example, the civil aviation authority compared the development status of other international hubs in all their annual reports. China dedicated one chapter of analysis to international comparison in the long term master plan of expressway and railway development document(*China National Expressway Network*

Plan 2004). In the planning process of regional development, performing comparisons are more than necessary. For the decision makers in the region, it is critical to know the position of the region within the country. For the national level decision makers, it is critical to have a benchmark tool and decide the approaches they are taking, a balanced approach or an unbalanced development approach.

In order to perform comparison, we firstly need to have a measurement. This research will firstly set up a measurement and then perform comparisons.

1.2 Targeted audiences

The targeted audience includes the following 1) policy makers at national level and planners who develop long-term plans for national infrastructure development; 2) policy makers and planners who develop long-term plans for a country’s regional development; 3) International organizations who provide policy advisory service and infrastructure investments across the globe.

1.3 Limitations on existing study

1.3.1 Statistic Indicator

Various kinds of indicators have been developed to measure, monitor and compare the infrastructure development. However, the most common used method is comparing the expressway, railway and air transport network in the term of total length of network, density, total turnover, turnover per capita. These indicators are basically the comparison of first-hand data, but it cannot reflect the social-economic, demographic and geographic condition in each country, thus it is hard to draw a theoretic profound conclusion.

The minister of the Ministry of Transportation of China announce the news proudly that “the total length of our expressway network will be as the same as in the United State in two or three years.” (Xinhua 2010) However, whether we really need so many expressway? Why this comparison and the target setting is rational? On the other hand, if we take other modes into consideration, the question will be: will it be better to invest in railway sector? Facing the fact, road, railway, air transport investment decisions are managed separately by different Ministries in China, they are not easy to corporate with each other for the coordinated decision. An objective method which enables an evaluation without subjective policy tendency is needed.

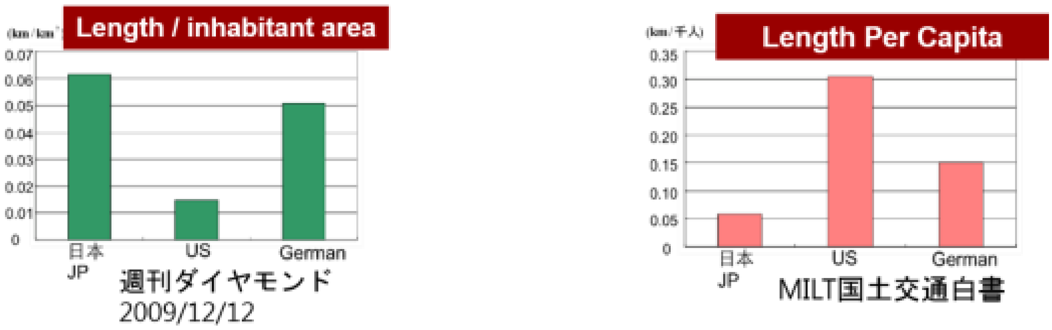


Figure 2 Opinions on Japan’s expressway network: media V.S Ministry of Transport
(Source: Diamond Weekly 2009/12/12, Ministry of Transport White Paper)

In extensive reports provided by the international organization, there are attempts to make an assessment of the development level. However in many cases the statistic indicators listed above are the only option available to make a quick diagnose. The World Economic Forum have annual globe updates on air transport infrastructure using data consolidated from ICAO and IATA, in order to inform the air transport competitiveness across globe. However, the evaluation perspectives are quite limited. Only airport density.(Schwab 2011)

The biggest limitation is that the most of the existing statistic indicators are not capable to capture the economic, demographic and geographic differences in a theoretic way. I will provide another example to illustrate why it is important. I will take the High-Speed Railway development in China for example. In recent 10 years, China constructed a massive amount of High Speed Railway and upgraded many existing lines into an operational speed more than 200 km/hour (Ollivier, Sondhi, and Zhou 2014). Figure 3 shows the HSR network in operation, under construction and planned in China as Oct.1 2014. The HSR network length in operation (including the lines with more than 200 km/hour) already reached to 19000 km (Xinhua 2016). If you compare the quantity of the HSR network in terms of length, the network in China is much longer than any other countries in the world. However, shown as Figure 4, the results of conclusions will be totally different if you comparing the length per land area, the length per capita and the length per GDP capita.

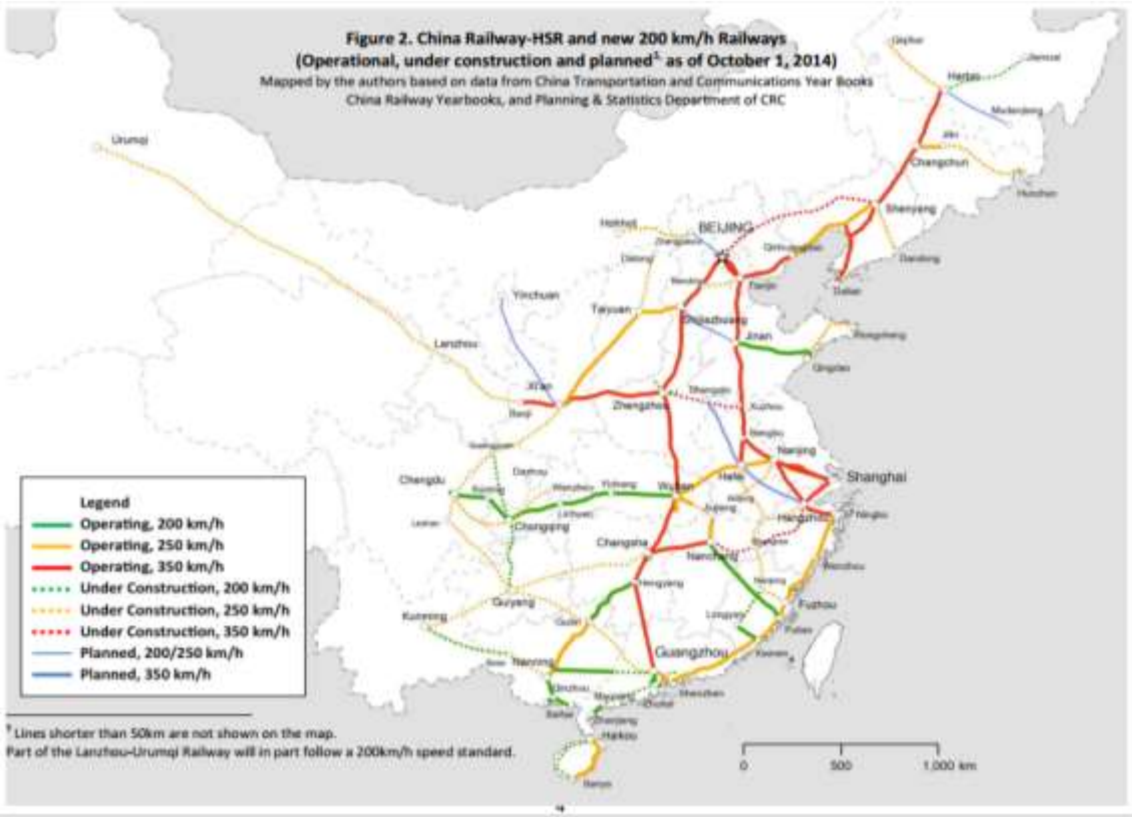


Figure 3 China Railway HSR and new 200 km/h Railways (Source: World Bank Report)

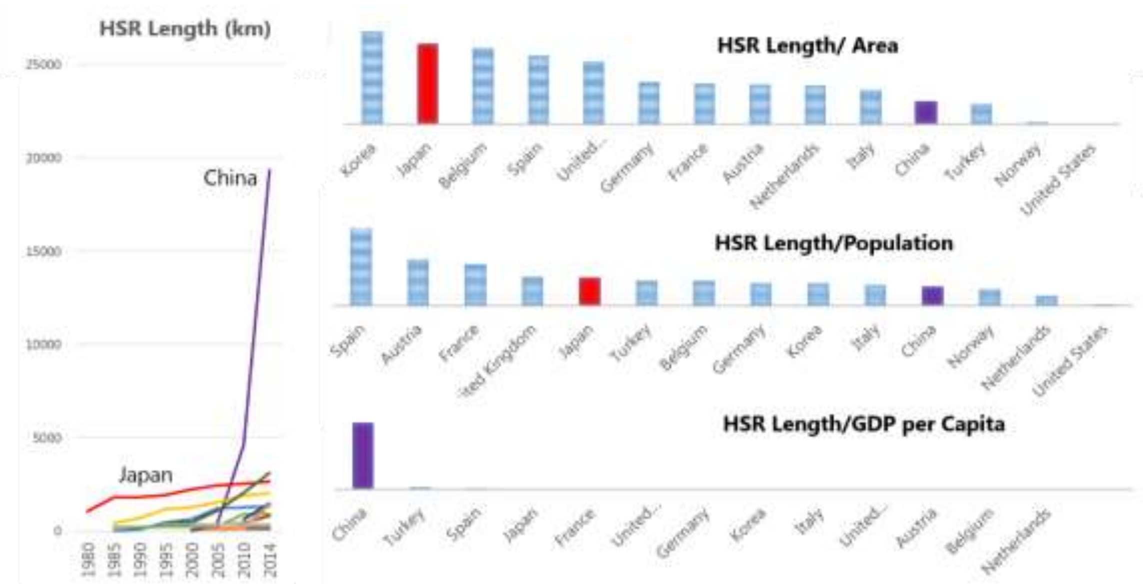


Figure 4 The complexity: comparing the HSR length in 2014 (Source: author complied the data)

The above figures reveal the issue of complexity of international comparison. The single input indicators could not capture the differences of the essential factors which drives the transport needs.

In conclusion, the statistic indicators aiming at measuring the development level of inter-regional transport infrastructure are not explicitly defining what the development level is. It is also has the limitations that the indicators cannot reflect the economic, demographic, and geographic needs in one indicator. This research will contribute in the way that an explicitly development level is defined and more importantly the method capture economic, demographic, and geographic needs in the development level comparison.

1.3.2 Accessibility index to evaluate the network connectivity or accessibility

Improve accessibility is one goal of transport infrastructure. Therefore, it is also one perspective to be evaluated as development level. Accessibility indexes are another type of indicators attracts a lot of theoretic researches and have been applied widely in the planning process. In general, it focus on the measurement of one fundamental function of transport infrastructure: improve the accessibility of people and goods to other facilities and activities. Furthermore, as transport infrastructure normally forms a network and where the network sometimes has hierarchy, many accessibility research considered the network and hierarchy effects on the accessibility issues. In measuring accessibility, there are several kinds of measurement: the physical distance, the time and monetary cost of accessing the infrastructure etc.

The simplest and widely used accessibility index can be described as following: a certain portion of population can access a certain type of transport infrastructure within a certain time or a certain distance. Many governments use this kind of index as planning criteria or for goal setting. Comparing to the statistic indicators mentions in 1.2.1, it more implicitly considered the fundamental function of transport and at the same time add the consideration of population.

A more detailed kind of accessibility index is taking more detailed and specific network attributes into calculation. For example, Murayama (Yuji 2000)using shortest path method to track the changes in Japanese railway network by calculating the total travel time from original city to other cities using shortest path. It will enable to track of impact of time saving changes in a comparably accurate way. The disadvantage is that, it requires more detailed network and spatial data of the country and modeling cost. The index developed in my research has the advantage that it only requires comparably simple data inputs.

Black (2003) introduced an index consider the topological properties of a network to describe the transportation network, however the index may be more suitable for a telecommunications where the major concern is how various nodes are connected to each other. Nodes analysis is widely applied in the airport and flight network.

By considering the actual travel distances between nodes through a network need to be considered, Wang (2009) develop an index called "Nodal accessibility coefficient" Ai=Di/($\sum Di/n$) (i=1,2….n) where Di=$\sum_j \ l_{ij}$ the total transportation distance from node "i" is defined as the i_{th} row sum of L matrix L=$[l_{ij}]_{ij}$. Smaller Nodal accessibility coefficient corresponds to a better accessibility. Wang (2009) use this coefficient to evaluate Chinese railway network expansion. The calculation of L matrix and Di need comprehensive route map of each country, it is possible to calculate other countries' value.

However, all the above methods are still difficult to find the relative position taking the social-economic, geography, demography characteristic into consideration. They also requires more detailed data inputs and computation time.

1.3.3 Performance and Quality benchmark

Many performance and quality benchmark indicators and associated methods have been developed with the focus on the operational and service performance evaluation. Especially the benchmark practices are more performed in the civil aviation sector. However, the indicators and methods focused on infrastructure performance and quality benchmark are quite limited. Among them, it either focused on strategic important infrastructure, for example, international airports, or focused on a specific area and scope.

Regarding railway operational performance, Milian(1997) use train frequencies and average schedule delays by route length to evaluate the railway and air networks quality in West, Central and Eastern Europe.

Regarding airports, several Airport Performance Benchmark Manual is developed to evaluate each individual airport's performance by using comprehensive data provided by major airports. The most established benchmark in airport is *Airport Benchmarking Report* (Air Transport Research Society 2014). It provides the statistic overview of the major airports and the rankings. The report ranks the major airports in the world in various perspectives, which are based on structured customer surveys across the globe. The limitations for the benchmarking report are 1) the scope of the report only covers major airports. For example they only cover Narita, Haneda, Nagoya Central Japan, Kansai airports in Japan. It is far from efficient to have a comprehensive review of the whole nation's status; 2) more importantly, the focus of the report is individual airport rather than a whole nation. 3) The evaluation is based on objective view from the user including the passengers, airlines and professional staff. However, a nation-wide evaluation has not been developed.

The World Economic Forum have annual globe updates on air transport infrastructure quality. They try to provide assessment on the national air infrastructure quality in order to inform the competitiveness of the air transport system. The outputs of the evaluation are based on structured survey results (World Economic Forum 2010-2011), they asked the question of how would you assess passenger air transport infrastructure in your country using a scale from 1 to 7 (where 1 is extremely underdeveloped, and 7 is extensive and efficient by international standards) in the Executive Opinion Survey.

1.3.4 Logistics Performance Index

Logistics Performance Index is one international comparison approach developed by World Bank (World Bank 2016) for the transport and more specifically the logistic system, which allows the comparisons across 160 countries. I will introduce and discuss more on this index.

The international score of logistics performance uses six key dimensions to benchmark countries' performance and also displays the derived overall LPI index. 'The scorecard allows comparisons with the world and with the region or income group' It helps country and international organization to identify gaps as well as learn from other countries.

The logistics performance (LPI) is the weighted average of the country scores on the six key dimensions (World Bank 2016):1) Efficiency of the clearance process; 2) Quality of trade and transport related infrastructure; 3) Ease of arranging competitively priced shipments;4) Competence and quality of logistics services (e.g., transport operators, customs brokers);5) Ability to track and trace consignments;6) Timeliness of shipments in reaching destination within the scheduled or expected delivery time. Among the six dimensions, they also evaluate the infrastructure and the associated services. Figure 3 shows the LPI rankings in the year 2016, where I used the interactive tool to present the top 30 countries. The website also provide interactive tools to show the 6 dimensions scorecards which demonstrate comparative performance of the country using a scale from 1 to 5 relevant to the comparison groups (Shown as Figure 4).

Regarding methodology of the LPI index, similar to the Airport Benchmarking Report, the index is based on the survey results of logistics professionals. The key dimensions are decided from empirical and theoretic researches. In order to make it international comparable, only the structured survey is not enough, they also selected the professionals who operates internationally. It is an objective evaluation on the supply and the operation needs from the point view of logistic operators, with a standard ‘ruler’.

Global Rankings 2014

DATA TABLE

LPI Global Rankings *2014*

(Toggle Rank and Score for Subindicators)

Country	Year	LPI Rank	LPI Score	Customs	Infrastructure	International shipments	Logistics competence	Tracking & tracing	Timeliness
Germany	2014	1	4.12	4.10	4.32	3.74	4.12	4.17	4.36
Netherlands	2014	2	4.05	3.96	4.23	3.64	4.13	4.07	4.34
Belgium	2014	3	4.04	3.80	4.10	3.80	4.11	4.11	4.39
United Kingdom	2014	4	4.01	3.94	4.16	3.63	4.03	4.08	4.33
Singapore	2014	5	4.00	4.01	4.28	3.70	3.97	3.90	4.25
Sweden	2014	6	3.96	3.75	4.09	3.76	3.98	3.97	4.26
Norway	2014	7	3.96	4.21	4.19	3.42	4.19	3.50	4.36
Luxembourg	2014	8	3.95	3.82	3.91	3.82	3.78	3.68	4.71
United States	2014	9	3.92	3.73	4.18	3.45	3.97	4.14	4.14
Japan	2014	10	3.91	3.78	4.16	3.52	3.93	3.95	4.24
Ireland	2014	11	3.87	3.80	3.84	3.44	3.94	4.13	4.13
Canada	2014	12	3.86	3.61	4.05	3.46	3.94	3.97	4.18
France	2014	13	3.85	3.65	3.98	3.68	3.75	3.89	4.17
Switzerland	2014	14	3.84	3.92	4.04	3.58	3.75	3.79	4.06
Hong Kong, China	2014	15	3.83	3.72	3.97	3.58	3.81	3.87	4.06
Australia	2014	16	3.81	3.85	4.00	3.52	3.75	3.81	4.00
Denmark	2014	17	3.78	3.79	3.82	3.65	3.74	3.36	4.39
Spain	2014	18	3.72	3.63	3.77	3.51	3.83	3.54	4.07
Taiwan	2014	19	3.72	3.55	3.64	3.71	3.60	3.79	4.02
Italy	2014	20	3.69	3.36	3.78	3.54	3.62	3.84	4.05
Korea, Rep.	2014	21	3.67	3.47	3.79	3.44	3.66	3.69	4.00
Austria	2014	22	3.65	3.53	3.64	3.26	3.56	3.93	4.04
New Zealand	2014	23	3.64	3.92	3.67	3.67	3.56	3.33	3.72
Finland	2014	24	3.62	3.89	3.52	3.52	3.72	3.31	3.80
Malaysia	2014	25	3.59	3.37	3.56	3.64	3.47	3.58	3.92
Portugal	2014	26	3.56	3.26	3.37	3.43	3.71	3.71	3.87
United Arab Emirates	2014	27	3.54	3.42	3.70	3.20	3.50	3.57	3.92
China	2014	28	3.53	3.21	3.67	3.50	3.46	3.50	3.87
Qatar	2014	29	3.52	3.21	3.44	3.55	3.55	3.47	3.87
Turkey	2014	30	3.50	3.23	3.53	3.18	3.64	3.77	3.68

Figure 5 Logistic Performance Index Global Ranking 2014

(Source: World Bank http://lpi.worldbank.org/international/global)

This research focused on providing the international comparison tool for inter-regional transport infrastructure which will not limited to logistic purpose and the methodology will internalize the demographic, geographic and economic needs for infrastructure. The comparison method developed in this research are based on subjective evaluation. However, the LPI provides great insights on conducting international comparison cross the globe as well as how to present the results to the audience.

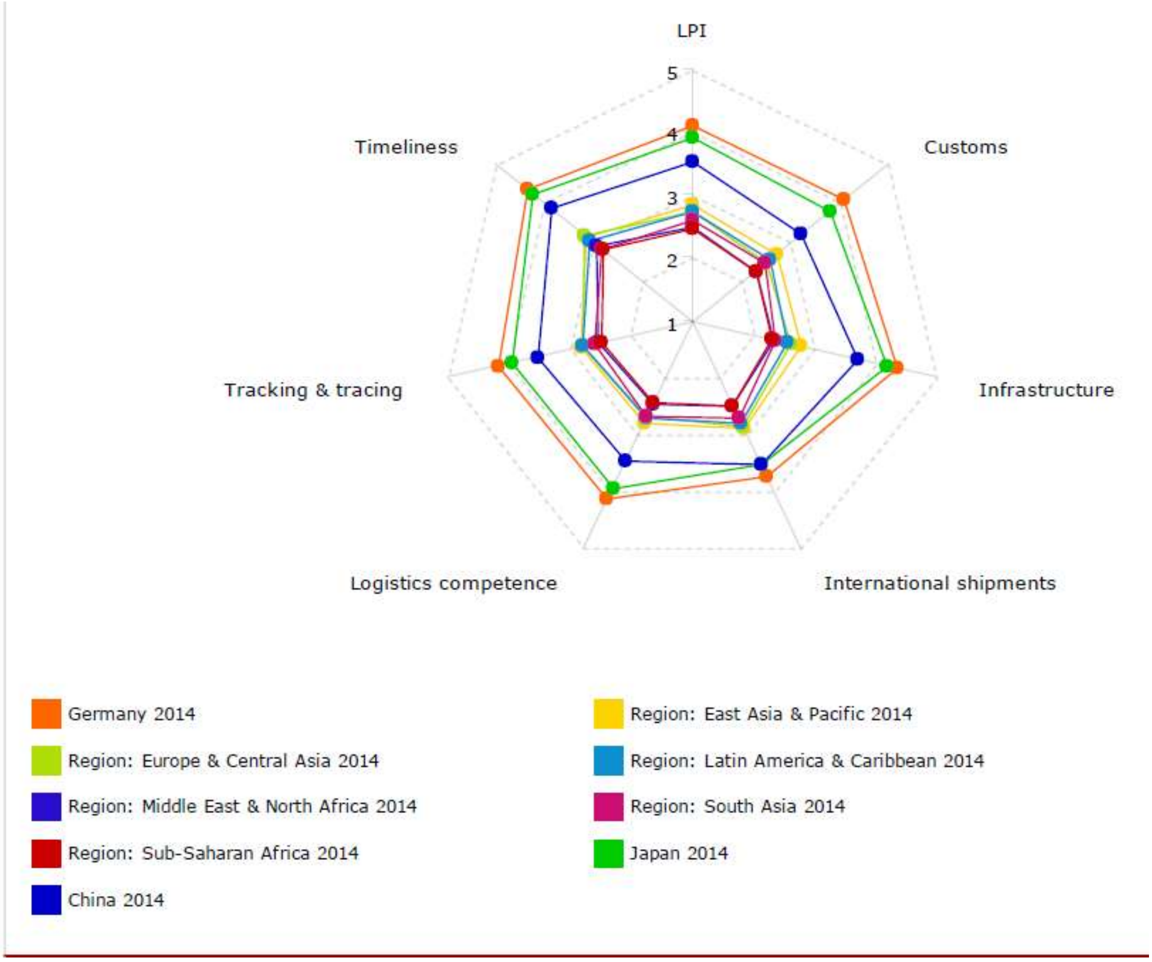


Figure 6 the 2014 Logistic Performance Index in six dimensions
(Source: World Bank LPI Website)

1.3.4 Normalized Development Level

Hitoshi Ieda (2010) and Kondo (2011) has developed a scientific methodology: Normalized Development Level and Normalized Land Characteristic Index for international comparison of the accessibility and capacity in expressway network with consideration of the difference of counties in their area, population and economic development level. I expanded the method to air transport infrastructure. Jie Xu (2012) expanded the method to High Speed Railway with focus on the speed and accessibility optimization. Yiping (2013) further expanded the method to port.

The cohesion of the methods for integrated assessment on all modes are needed. The improvement of components involved are needed. More importantly, applications on more countries and associated discussions have not been fully conducted. Integrated application on all modes in order to assess the overall development on inter-regional development are still lacking.

1.3.5 Assessment on multi-mode

It is almost a blank page on the attempts to conduct assessment of inter-regional transport infrastructure development covering all modes. The above development assessment methods and indicators are capable to conduct evaluation on a specific mode. But it is not capable with to provide an integrated or overall assessment on all modes.

As the transport modes for inter-regional transport are substitution goods and public goods, coordinated planning and investment planning are needed to cope with the demands. However, even the central government agencies (or the ministries in charge, consider the facts that institutional arrangements does not facilitate the coordinated planning on the inter-regional transport infrastructure) are driven by their own agenda to build one specific mode. Therefore, an assessment on the overall or (integrated) development level of inter-regional transport infrastructure is needed to facilitate the coordinated decision making. This research will fill this gap.

1.4 Structure of this thesis

The thesis will proceed as follows: In Chapter 2 and 3, I explain the construction of the framework of Normalized Development Level for international comparison. The focuses are i) shaping a definition of development level for inter-regional transport infrastructure; ii) formulate the details for all modes of transport. Chapter 4 is methodology improvements in order to apply the NDL to other scales. Chapter 5 is the application of the method at country level for all modes of transport, followed by policy discussion. In Chapter 6, the development level of each regions within a country is examined and discussed, focus on Japan and China. In Chapter 7, the NDL is applied to global region. Preliminary analysis is carried out for EU. Chapter 8 conclude the contributions and findings of this research as well as future works.

Chapter 2 Development of Normalized Development Level Index from Network Accessibility Viewpoint

In this chapter, the theoretical framework of the normalized development level index is introduced in detail. The questions laid out in chapter 1 will be answered. What is the level of development of inter-regional transport infrastructure achieved by different countries? Firstly, what is the definition of development in inter-regional transport infrastructure? Associated with this question is that what is the development supposed to achieve. Secondly, how to measure it, more specifically how to measure the achievement for the specific goal or set of goals. Thirdly, how to construct a cost-effective practical model.

Section 2.1 introduced the theoretical foundations underlying this research. Section 2.2 presents the general theory of normalized development level. Section 2.3 explained how to derive the key components of the NDL, the necessity, from network accessibility viewpoint. Section 2.4 presents how to specifically formulate the NDL for expressway, high-speed railway, railway and airport from network accessibility viewpoint. In later part of this chapter, Section 2.5 will present a powerful application of NDL, an integrated model formulation for all transport modes from network accessibility viewpoint.

2.1 Theoretical foundations underlying this research

2.1.1 What is the development level?

"What is development? And can you determine which countries are more developed and which are less? These are difficult questions." (Word Bank, 2004) Even World Bank is still defining the meaning of development and the measurement of poverty. However it concludes that to compare the development levels, we need to firstly determine "what development really means to us", "what it is supposed to achieve". "Then indicators measuring this achievement could then be used to judge countries' relative progress in development".(Soubbotina 2004).

In this research, we will define what is the development of inter-regional transport really means to us, what it is supposed to achieve and we derive the indicator to measuring the achievement.

It is very important. As the statistic indicators aiming at measuring the development level of inter-regional transport infrastructure does not explicitly define what the development level is, this research will contribute in the way that a explicitly development level is defined.

2.1.2 Economy Theory: Optimal achieved when marginal benefit and marginal cost reach the equilibrium level.

In economy theory, the optimum or an efficient allocation will be achieved when marginal cost equals to marginal benefit. The social optimum (maximized sum of consumer surplus and producer surplus) will also be achieved. Then, It is also the efficient amount of good been produced. In theory, we could also derive the optimum amount of infrastructure using the marginal benefit and marginal cost equilibrium.

Then what is the necessity of a country for inter-regional transport infrastructure? We apply this principle to derive the optimum amount of infrastructure. **The optimum amount of infrastructure will present the necessity of a country at a certain time.**

2.1.3 Cost-Benefit Analysis for overall economic impact of transport project

The theory of the development level in this research is also based on the cost-benefit analysis, which is widely and commonly adopted for transport project appraisal, especially for economic evaluation. The framework of cost-benefit analysis for transport project appraisal is summarized as following based on a comprehensive note on economic evaluation of transport project prepared by World Bank Group (The World Bank Group 2005).

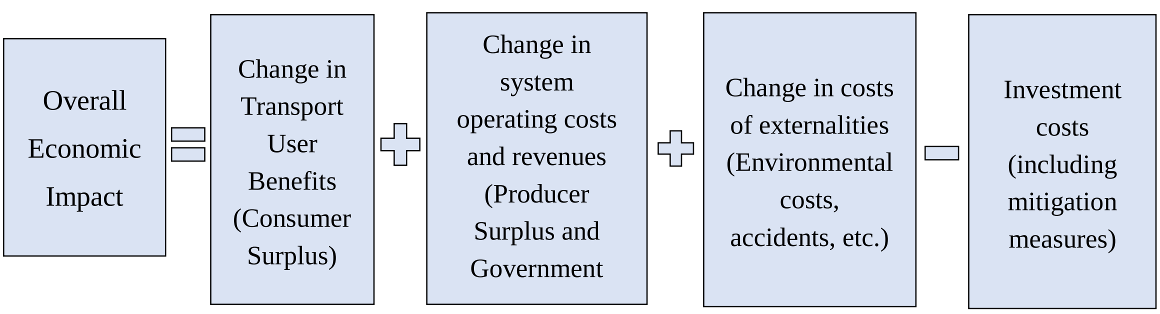


Figure 7 Basic calculation of overall economic impact of transport project

(Source: World Bank Transport Note 5)

This framework is widely adopted in a bottom up, project based evaluation. This research will applied this framework in national level, top-down evaluation. The formulation of benefits and costs of inter-regional transport infrastructure investment will be based on this framework.

2.2 General Theory of Normalized Development Level

Firstly the development level is defined as supply and demand (necessity) ratio. Secondly, the detailed definition of supply is introduced. Thirdly, the most important concept of the Normalized Development Level—The necessity--is derived using marginal cost and marginal benefit equilibrium. Later on, the unification and specification of the development level for each transport mode are introduced.

2.2.1 Definition of Development Level

Why we develop infrastructure to supply to the society? It is because there are needs (or say demand, necessity). Then what is development in transport really means to us and what it is supposed to achieve? Basically, we define the develop level as supply and demand ratio. Let's think in this way. If the needs are very large in country A, but you only supply a tiny amount of infrastructure. In contrast, if the need in country B is very small, but you supply the same amount of infrastructure. Which country is more developed? If you only consider the amount of infrastructure supplied, you will reach a wrong conclusion.

Hence, we define development level α as following:

$$\boldsymbol{\alpha} = \frac{\boldsymbol{Supply}}{\boldsymbol{Necessity}} \qquad (2.1)$$

The detailed definition of supply and necessity in this research will be defined in the following sections.

2.2.2 Definition of supply in the development level

Supply of inter-regional transport infrastructure can be categorized in two folds: 1) the provision of physical infrastructure and facility itself. Or in other words, the stock of infrastructure. I.e. the expressway constructed, the railway track, airport. 2) The quality of the infrastructure. For example, the design speed of railway track, the capacity, the life cycle length of a certain type of infrastructure, the artistic design of these infrastructure etc. 3) the provision of transport operation service. For example, long distance buses, trains running on the track at a certain frequency at certain comfortable level, flights offered at the airport to other airport at a certain frequency.

In this research, the supply focuses infrastructure provision. In other words, the stock of infrastructure. The physical infrastructure is the foundation for the service operation. In comparison to service operation, the physical infrastructure more rely on government investment. And practically speaking, considering the physical infrastructure data is already very limited, the comparable transport operation data across countries for railway and expressway are even more limited.(Canning 1998)

In general, the supply is length of the infrastructure stock reflect the spatial accessibility of the transport network and capacity of the infrastructure stock. The detailed numerical form of the supply will be introduced in later sections.

2.2.3 Concept of Necessity

The concept of necessity is developed firstly by Ieda (2005) for expressway. And further enriched by (Hitoshi Ieda, T. Igo,Y. Kondo 2011) for expressway, developed for airport (Zhao 2011), developed for High Speed Rail (Jie 2012), expanded to port (Hitoshi Ieda,Yiping Le,Xu Jie 2013). **My research further enriches this concept through justifying, unifying them, adding conventional railway mode and integrated all modes.**

Necessity of a country at a certain time is expressed in a theoretical optimum amount of infrastructure. The theoretical optimum amount of infrastructure is derived by an equilibrium status of marginal benefit and cost in economy theory. Applying the economy theory to inter-regional transport, it is if the marginal benefit of constructing a unit amount of new inter-regional infrastructure is equal to marginal cost of constructing and operating a unit amount of new inter-regional infrastructure, the optimal status achieved with the optimal amount of infrastructure. It is also the point of efficient allocation of infrastructure occurs.

2.2.4 Cost-Benefit Analysis Framework and Necessity

The application of cost-benefit into formulating necessity has following different points and advantages: Firstly the scale is different. Cost-benefit analysis is widely and commonly used for project based appraisal. Or in other words it is a bottom up approach. My research is a top-down approach. Secondly, the conventional cost-benefit evaluation is based on a proposal outlining the magnitude of provision of infrastructure. However in this research, the positive economic impact is reached at the equilibrium status of marginal benefit and cost, without setting a fixed magnitude of infrastructure provision. Thirdly, in order to trade off the model construction and data cost, my research focused on the main benefit of consumer surplus and include the main benefit of producer surplus and government impact implicitly as well as the main part of investment costs. Since the externalities cost normally is comparably small in the transport project comparing to other benefits. I will not include it explicitly.

Why simplification is meaningful? Take the development GDP index for example. “The productivity with which countries use their productive resources (physical capital, human capital and natural capital) is widely recognized as the main indicator of their level of economic development. Theoretically, the economists should calculate how productively each countries are using their capital. However, such calculations are extremely challenging. In practice economists use gross national product per capita or gross domestic product per capita for the same purpose. These statistical indicators are easier to calculate, provide a rough measure of the relative productivity ” (Soubbotina 2004)

Even in Cost-Benefit Analysis itself, ideally the process should cover all impacts. However it will need extensive data and modeling which may cost heavily in terms of monetary cost and time cost. Therefore, in practice that the Cost-Benefit Analysis excludes the insignificant impacts. Also because the purpose of the conducting the analysis is to see whether the project is economically beneficial choosing from alternatives. (The World Bank Group 2005)

In the below part of the chapter, how to construct the benefit component and the cost component will be the key to derive the necessity. I will discuss the main impacts we included in the research.

2.3 Basic Theory of Deriving Necessity from Network Accessibility viewpoint

2.3.1 Conceptual Framework

As introduced above, the necessity of a country for inter-regional transport infrastructure will be derive by the optimum amount of infrastructure, which will present the necessity of a country at a certain time. The optimum amount of infrastructure will be achieved when the marginal benefit of providing additional unit of infrastructure equals to the marginal cost of the providing additional unit of infrastructure. On the other hand, constructing new infrastructure will need investment cost.

The optimal supply will be achieved by minimizing the sum of benefit and cost. In following parts, I will introduce how to construct the benefit and cost components.

	Benefit		Cost
Minimize=	Time cost of traveling in the given network for given population	+	Construction Cost of the network expansion

2.3.2 Definition of Network Accessibility Perspective

A country needs transport infrastructure, because the expansion of network will reduce the time of connecting origination and destination in terms of 1) accessing and egressing time to the network; 2) the time traveling at the (higher speed) network. In reality, the infrastructure also has a capacity limits, if the user exceed the capacity limits of the certain section of infrastructure, it will cause congestion and further increase the time cost.

In first step of the research, we ignore the capacity issues only focus on the accessibility. We doing this simplification for following reasons: 1) The most important decision at the beginning is “build or not build” hence it is a question of “connect or not connect” which measuring the ability to access the network and using the network. 2) In most of the cases the provision of new infrastructure will accommodate the needs which will not cause congestion at the initial phases. 3) The data of capacity is much more difficult to collect. The data related to capacity is normally categorized into quality of the infrastructure. (Canning 1998). In Chapter 3, we will discuss how to evaluate the capacity at the same time.

2.3.3 Benefit of providing additional unit length of infrastructure.

As discussed above in the economic impact evaluation of transport projects, **the main benefit of transportation project comes from time saving.** Then here is **the reduction of time cost of travelling in the given network for given population.**

Considering a country as a large square are with grid shape of inter-regional transport network as below. If the network length increase it will results in the network density increased, the access and egress time from origination to destination. If we assume that the newly increased length will evenly let the network density increase. The population of the country is evenly distributed. We will discuss the above simplification and assumptions later. Then we could form the benefit as following:

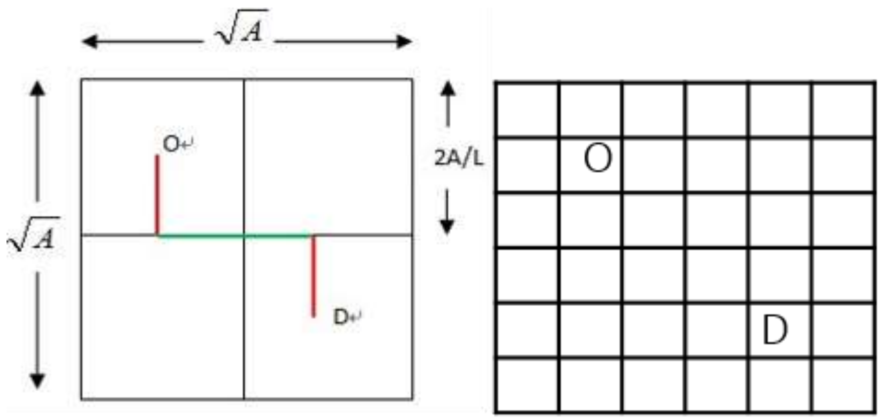


Figure 8 Network Illustration

Country size is A ; Network Length of the transport infrastructure is L; Travel speed on the network is V ; Travel speed on the normal network (the network used to access the higher speed network. We also assume the network exists) is V_N. Number of people use the network is $k_p P, P$ is the population of the country, k_p is consistent; Time value of users is $k_I I$, where I is GDP per capita, k_I is constant; l is average total travel distance on the network; Then the average access distance to the higher speed network is approximate equals to $\frac{2A}{L}$

1) Access and Egress time reduction due to network expansion:

$$\frac{2A}{L} \cdot \frac{1}{V_N} \tag{2.2}$$

2) Time reduction when traveling at higher speed network:

$$(l - \frac{2A}{L}) \cdot \frac{1}{V} \tag{2.3}$$

3) Number of people use the network: $k_p P$
4) Time value of users: $k_I I$ (The rationale of choosing GDP per capita as the time value will be discussed later)

Therefore, the total time cost of traveling in the given network for given population can be described as following:

$$k_a \frac{l}{V} PI + k_{b1} \frac{A}{L\Delta v} PI \tag{2.4}$$

$$\text{Where: } \frac{1}{\Delta v} = \frac{1}{V_N} - \frac{1}{V} \tag{2.5}$$

In summary, the formation of benefit component is based on a sound transport theory, within which it captured the geographic, demographic and economic factors contributing to the necessity. This the main advantage of this method compared to other methods.

Discussions on the assumptions and limitations will be introduced in section 2.3.6.

2.3.4 Cost of providing additional unit length of infrastructure.

The cost of providing additional unit length of infrastructure is (C). For the spatial accessibility assessment, the unit in expressway is unit length, the unit in airport is number of runway, and the unit in HSR is length. The key factors influence the cost are 1) **Economic factor**: affected on the material price, labor cost and land cost; 2) **Demographic factor**: affected on the land cost. i.e as other factors holds, the higher population density the higher land cost. 3) **Geographic factors**: here we mainly discuss the earthquake's impact on the cost part, and the inhabitant area ratio.

$$f(C) = f(Network,\ Population,\ GDP, Geo) = k_c f(c) L \tag{2.7}$$

Regression analysis of the construction cost are conducted using construction cost data from actual inter-regional transport infrastructure projects. The details will be described in later sections.

2.3.5 Deriving the optimal amount of the infrastructure for necessity

The optimal supply will be achieved by minimizing the sum of benefit and cost, which is total cost. We denote the total cost as TC ;

$$TC = k_a \frac{l}{V} PI + k_{b1} \frac{A}{L\Delta v} PI + k_c f(c) L \quad (2.8)$$

Hereby, the when TC is minimized, the optimal length of network ---The Necessity --can be calculated by following equation:

$$L^* = k\sqrt{\frac{PAI}{c\Delta v}} \text{ , where } k \text{ is constant} \quad (2.9)$$

2.3.6 Discussion of the assumption, simplification and limitations

The simplification of the network into grid shaped network and evenly distributed is mainly for simplifying the calculation and model formality. Several researches adopted this kind of simplification in complex network analysis (Griswold 2013). The growth of the network will be redistributed into the network evenly. This simplification will help the model to do the optimization easily as well as considering the existing infrastructure stock on the network.

The simplification of the population evenly distributed is also mainly for simplifying the calculation. Although it might not be able to reflect the concentration of population in some country. But as this research will proceed the domestic region comparison, the discussion of that will minimize the impact of the concentration of population at the country level.

Average travel distance: In this formulation, we assume that the average travel distance for a country keeps constant. This simplification will contribute to a cost-effective model construction. It might look like a strong assumption. However, (Jin, Wang, and Liu 2004) concluded that the average distance for domestic air travels in China and US did not change so much across time.

Regarding speed difference on the network, how to treat the speed difference on the normal network and higher speed network. As the speed travelling on the normal network might be difference across countries due to the speed limits and road condition as well as the user may choose different modes to access the higher speed network, we need to consider how to treat these difference. One approach can improve the consideration of the speed is get one universal value through regression analysis using the data collected from the real google map data.

In the expressway and HSR model, we assume that they can get on the expressway and exit the expressway network/ HSR network easily. This simplification is more acceptable in expressway network, however as the station interval on the HSR network is relatively large, there is a need to discuss further treatments. Based on current network model, the access and egress distance formal (2.2) can be slightly modified to address this issues accordingly.

2.4 Model Formulation for expressway, high-speed railway, railway and airport from network accessibility viewpoint

The general formulation of the supply and necessity has been introduced in the above chapter. Then in this section, we will formulate the necessity for expressway, high-speed railway, railway and airport from accessibility viewpoint. The formulation will be focus on the rationale of using the general formation developed above into specific mode. And summarize the cost component from previous studies and new calculation.

2.4.1 Formulation of Necessity for Expressway

The NDL firstly is developed based on expressway network. As the network density of expressway are normally the highest among all modes. The general mode with the simplification and assumptions fit very well for expressway. For example, as the network has the highest density then the approximation of access and egress distance will have the closest approximation.

Hence the Necessity for Expressway is described as following

$$L^* = k\sqrt{\frac{PAI}{c\Delta v_E}} \qquad (2.10)$$

where $\frac{1}{\Delta V_E} = \frac{1}{V_N} - \frac{1}{V_E}$, V_E is the speed travel on the expressway (2.11)

The economic, demographic data are compiled by the author from World Bank Databank (World Bank 2016), national accounts from EU Statistic (EU 2016) and various official national statistics authorities. The details of the data sources will be introduced in the ANNEX 2.

The supply is the length of expressway in the unit of km.

To form the construction cost of expressway, two sources have been used in this research. One is conducted by (Hitoshi Ieda, T. Igo,Y. Kondo 2011) using real construction cost data from 24 countries (2000-2008) and variables finally selected are I represent the GDP per capita, D represents the population density in inhabitant area, and one dummy variable E when the country have high risk of earthquake. The regression results are shown as following

$$c = 3.99 \times 1.9^{E} \times I^{0.81} \times D^{0.29} \tag{2.12}$$

(2.32) (4.79) (3.36) R^2=0.58

The other source is a study conducted by using data from 53 countries by David (OECD, 2007). I represents the GDP per capita. The sample size used by David is much larger and diversified than (2.12). The results obtained by David is described as follows.

$$Ln(C) = 25.9 - 3.517\ln(I) + 0.226(\ln(I))^2 \tag{2.13}$$

(4.66) (2.59) (2.76) N=53 R^2=0.26

In the application part of this thesis, I corrected and updated the input of data set in terms of inhabitant area and conversion of GDP in 2005 constant US dollar.

While doing country level comparison, as the across boundary traffic is increasing especially in EU, there is rising issues of how to consider passing traffic in the evaluation. In the previous studies, the consideration of across boundary traffic issue has not been fully incorporated. In chapter 4, how to further improve the model will be described there.

2.4.2 Formulation of Necessity for HSR

Jie (Jie 2012) tried the formulation of necessity for HSR from the accessibility and speed perspectives. In his study the optimization process for deriving the necessity involved speed as variable, which is not the constant. I unified the formulation in accessibility perspective and apply the formulation into application.

$$L^{*} = k\sqrt{\frac{PAI}{c\Delta v_H}} \tag{2.14}$$

where $\frac{1}{\Delta V_H} = \frac{1}{V_N} - \frac{1}{V_H}$, V_H is the speed travel on the HSR (2.15)

Although V_H is a constant in the above expression, for the input of the application part. The V_H is weighted average speed by section length and associated speed based on the best data available.

One important element of the L^* is construction cost. The construction cost of HSR used in this research are based on the data in the study of Jie (Jie 2012) from 43 lines in 11 countries. In Jie's research the, the final calculation contains the expression with the variable of speed of HSR in order to simplify the minimization process. In this research as the equation (2.16) is used to evaluate the accessibility with the assumption the speed travel on the network is constant. Then I choose another regression results (Jie 2012) which does not contains speed, but also has higher fit. I is GDP per capita, P is population. A Is Inhabitant area.

$$c = k + 1.05I + 0.095\frac{P}{A} + 20.404IE \quad (2.16)$$

(6.62) (4.89) (4.095) R^2=0.74

2.4.3 Formulation of Necessity for Airport

The formulation of the Necessity for Airport is similar to other modes. The difference is that I define and simplify the catchment area in the shape of circle and the average distance to access the airport is calculated in integrating the distance within the circle. Then the total cost can be expressed as following.

$$TC = k_{a4}\frac{l}{V_A}PI + k_{b4}\frac{\frac{P_d}{3}\sqrt{\frac{A^3}{\pi n^3}}}{V_E}PI + k_{c4}cn \quad (2.17)$$

Minimize the total cost, then the necessity is derived as

$$n^* = \sqrt[3]{\frac{\mathrm{I}^2\mathrm{P}^2\mathrm{A}}{9\mathrm{v}^2\mathrm{c}^2\pi}} \quad (2.18)$$

The main construction cost of airport is the land acquisition and runway construction which is proportional to expressway construction cost hence I use equation (2.13) to calculate the cost.

2.4.4 Summary of the formation

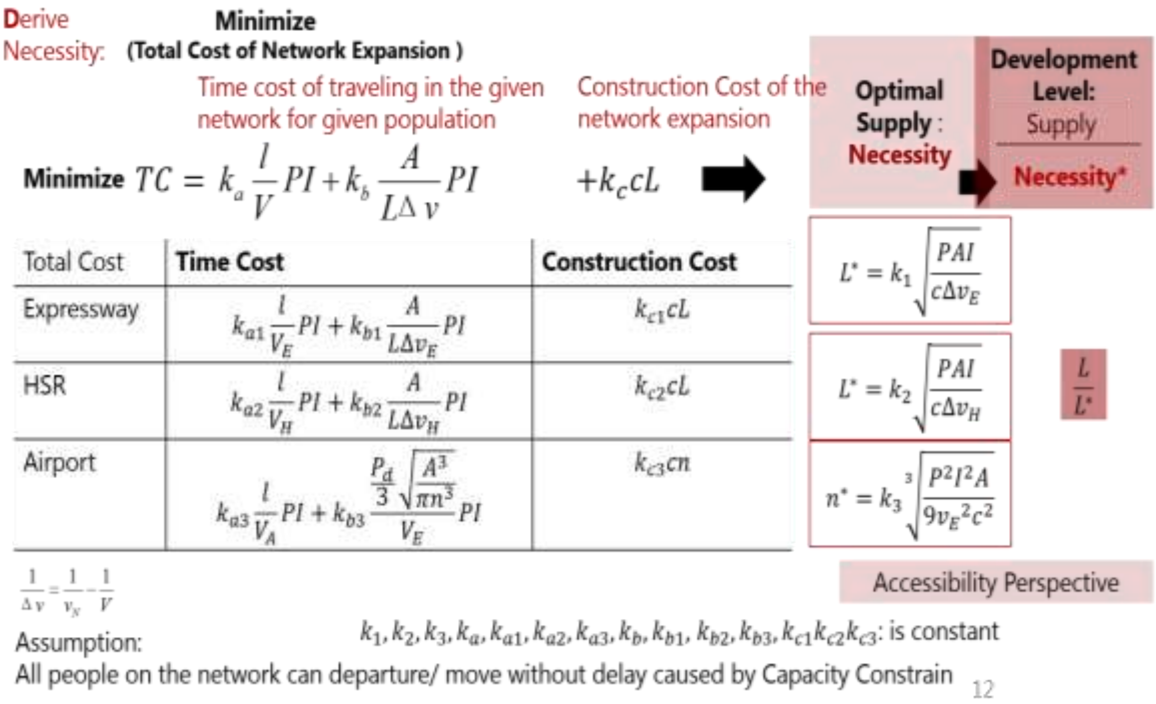


Figure 9 Summary of the formation (Source: Author)

2.5 The Normalized Development Level

Ieda (2005) firstly tried the Normalized Development Level. As defined and introduced before, the development level of a country is defined as α, which is the supply compared with necessity of the country.

$$\boldsymbol{\alpha = \frac{Supply}{Necessity}}$$

In comparison process, we choose a base country (or region) to compare with. The country's development level denotes as α_0. Then we compare the development level of any country against the base country as following. Then we denotes the Normalized Development Level as r_α from

$$r_\alpha \equiv \frac{\alpha}{\alpha_0} = \frac{\frac{S}{N^*}}{\frac{S_0}{N_0^*}} \tag{2.19}$$

It is important to notice that in this process the unknown parameters (constant) of the necessity part will be canceled each other with the assumption that they are in the generic form across country.

S Denotes the supply. In each of the modes, the numerical expression of S can be described as following:

1) The supply in expressway in the perspective of spatial accessibility: the length of the expressway in the unit of km, L_E
2) The supply in HSR in the perspective of spatial accessibility: the length of the HSR in the unit of km, L_{HSR}
3) The supply in the airport in the perspective of spatial accessibility: the number of airport, n

Regarding necessity, N^* denotes the necessity of the certain mode, S_0 denotes the supply of the base country, N_0^* denotes the necessity of the base country.

In the applications we will use this concept of Normalized Development Level to conduct comparison.

2.5.1 The comparative value

One thing should be noted is that higher NDL in a country does not always mean that its development is more preferable than those in a country with lower NDL. Firstly, because It provides a comparative view. It is not a judgment of good or bad. Secondly, although NDL has captured fundamental aspects of transport infrastructure. Hence, when we interpret the NDL results, we need to mind the definition before head.

2.6 Integrated Model formulation for all transport modes from Network Accessibility viewpoint

There are very limited research which can reveal the development level covering all modes of inter-regional transport infrastructure. With the completion of the development level for each modes and the Normalized Development Level in this research, the integrated NDL can be achieved.

Each mode at the certain year is compared with the base line year of national NDL 1 of Japan, which is the national level of Japan at the year 2010. Please note that the base country and base line can be changed based on your needs.

As NDL has been developed for each mode, I integrated the NDL for expressway, HSR and Airport by using the triangle to represent 1) the mode pattern; 2) and the integrated development level suggested by the size of the triangle. It is similar to the approach of LPI scorecard (World Bank 2016).The details of the applications will be discussed in Chapter 5 and 6.

Figure 10 Illustration of integrated NDL using triangle (source: author)

Chapter 3 Development of Normalized Development Level Index from Both Network Accessibility and Capacity Viewpoint

In this chapter, the development level assessment is expanded to one more dimension—Capacity of infrastructure. Section 3.1 introduce why it is important to expand the consideration of capacity and how is the basic theory developed. Section 3.2 presents the detailed model formulation for expressway, high-speed railway, railway and airport from network accessibility and capacity viewpoint.

3.1 Basic Theory from Network Accessibility and Capacity Viewpoints

3.1.1 Why need to consider capacity?

Why need to consider capacity? In the accessibility development level, we assume that anyone can use the network without any capacity constraints. However in reality, there are many countries are suffering from the capacity constrain issues. Even take airport transport infrastructure for example that IATA states that Latin American region is lack of adequate capacity to meet the rising demand.(Cossio et al. 2012) Take Brazil for example, there are 13 airports has capacity constraints.(Cossio et al. 2012). Hence we would like to expand the development level assessment considering both accessibility and capacity.

The difficulty involved in this development is the data availability. Especially the historical data of capacity expansion.

3.1.2 Conceptual Framework and Definition of Network Accessibility and Capacity

We apply the same framework and economic foundation described and introduced in Chapter 2. The difference is that we reflect the capacity impact into the speed difference on the network shown in the following concept diagram as well as the summary of model formulation for each modes. The expressway modes are based on Kondo (2011) and others are developed by the author.

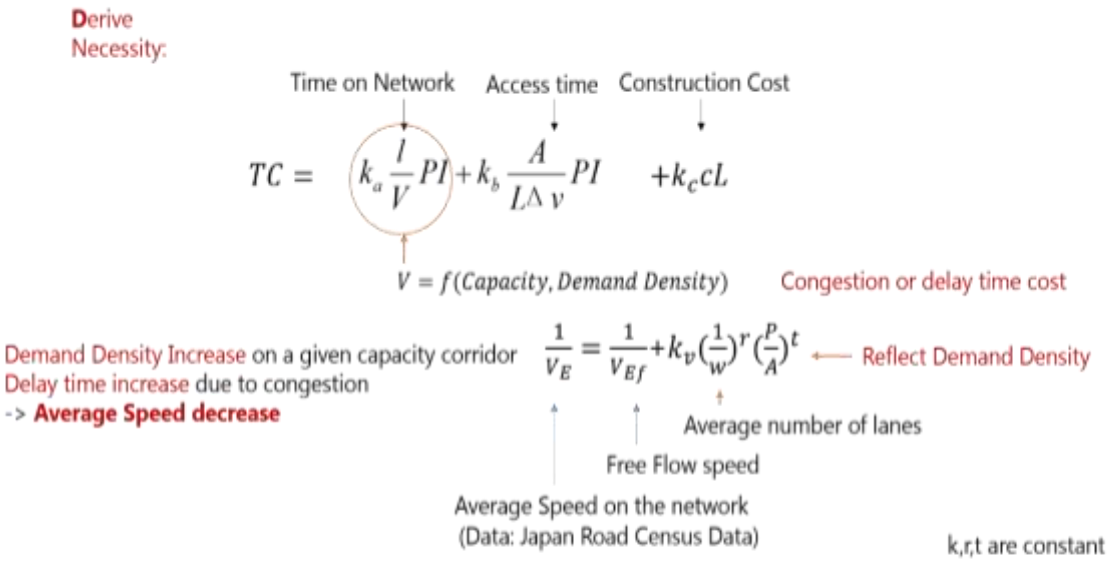


Figure 11 Framework Summary (Source: author)

In Chapter 2, we assume that there is no capacity constrain on the network. They people could travel at the free flow speed or the theoretic speed of the network. However, when the network facing capacity constrain, the speed will be affected. The relationship of the speed and capacity is the key to form the necessity for this new index.

The components to derive necessity is as the same as the (2.8), we use (3.1) to reflect the demand density. Delay time and average speed relationship in expressway. The definition the of the variables are as the same as in Chapter2. t, r is the unknown parameters to be estimated using road census data. w denotes to the average width of the expressway which represent the lane number and the width of the lane.

$$\frac{1}{V_E} = \frac{1}{V_{Ef}} + k_v \left(\frac{1}{w}\right)^r \left(\frac{P}{A}\right)^t \tag{3.1}$$

Hondo (2010) estimated as following $t = 0.34$ (t-value 1.54), r=0.93 (t-value 2.66), $R^2 = 0.41$.

Applications will be introduced in later chapters.

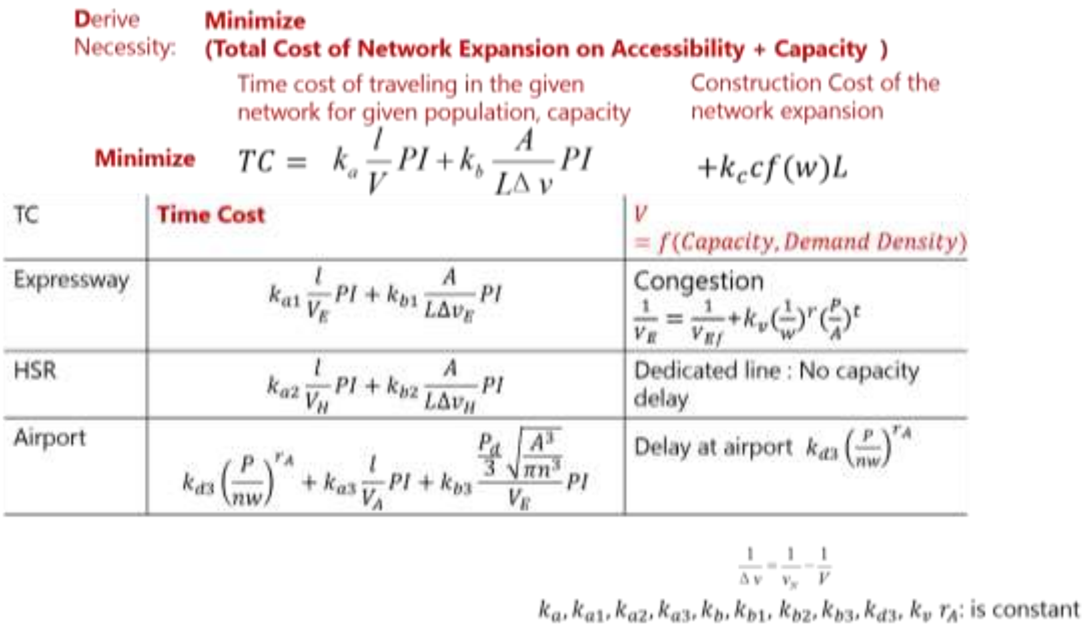


Figure 12 Summary of the formation (Source: Author)

Airport: The airport capacity is primarily determined by the runway capacity(*Airport Runaway Capacity and Delay: Some Models for Planners and Managers* 1983) . The demand density of the airport theoretic traffic $\frac{P}{nw}$ and the delay time is expressed in (3.2) n is the number of airport, w is the length of the runway in the unit of km. r_A is unknown parameter to be derived from theoretic capacity and delay relationship, here $r_A = 1.5167$ (Zhao, 2011). k_{d3} is constant.

$$k_{d3}\left(\frac{P}{nw}\right)^{r_A} \tag{3.2}$$

The necessity will be derived by obtaining the optimal by minimization of the total cost.

Chapter 4 Expansion of the Method to Region and Pan-global Regions Comparison

NDL is not only capable to do international comparison at country level. It also has potential to apply to other different scales. For example, conduct development level comparisons for smaller regions within a country. In order to do so, we need to handle the problem caused by passing traffic as the above model has not fully consider the passing traffic. As the interactions between countries on the surface transport are growing, actually without considering passing traffic at the country level comparison also caused some problem. **One main contribution of this research is that it provides solutions to solve the through traffic issues in model formulation which enable the NDL to be applied to smaller scales as well as country level with improvements.**

Section 4.1 introduce why we need to consider passing traffic on the network in the NDL model. Section 4.2 present why and how to apply gravity model to solve the passing traffic issue. Section 4.3 introduce my attempts to simplify the geographic impact on passing traffic in addition to section 4.2.

4.1 Consideration of passing traffic on the network

4.1.1 Definition of Passing Traffic on the network

For each domestic region (or country) i, the gross traffic on the infrastructure network consists of three parts:

Part 1: The traffic within the region T_{ii},

Part 2: The traffic from the region i to other regions $\sum_j T_{ij}$, the traffic from other regions to region i , $\sum_j T_{ji}$

Part 3: The traffic passing the region $\sum_m \sum_n T_{mn}$ where $m \neq i \text{ or } j, n \neq i \text{ or } j$

4.1.2 Why we need to consider passing traffic in the model

At country level, there are international traffic from country A to country C bypass country B. Then the infrastructure of country B needs to shoulder the international passing traffic. This issue has not been explicitly considered in previous studies. However, many countries in Europe continent are handling a significant proportion of international traffic shown in the following figure (European Commission 2011).

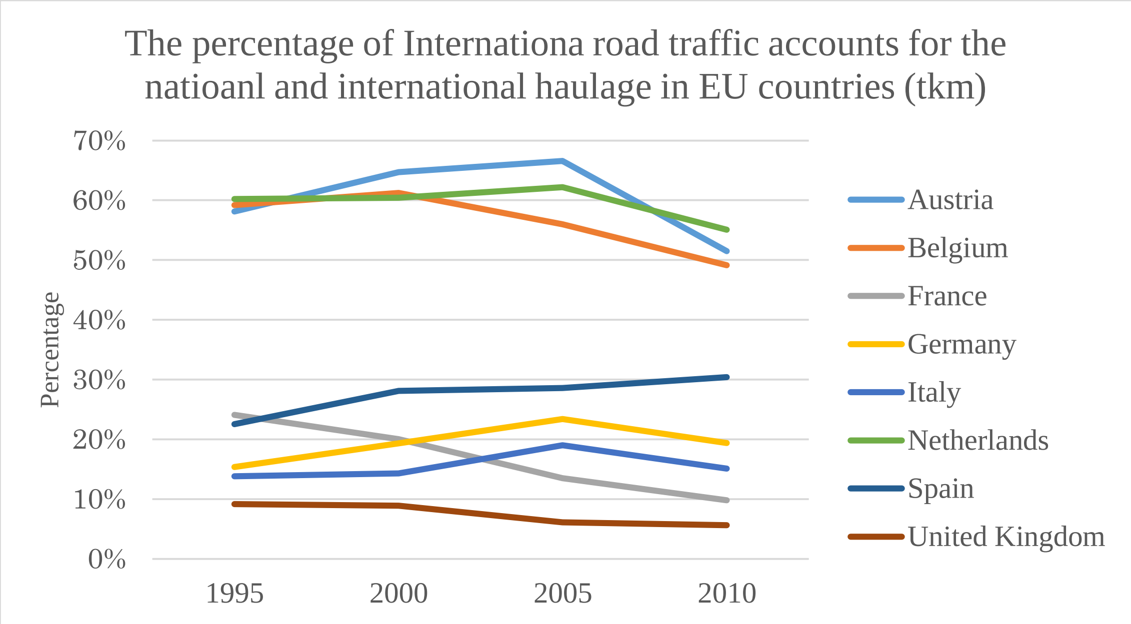


Figure 13 the % of international road traffic accounts for the national and international haulage in EU countries (Source: EU statistic, author complied)

The international traffic on the roads accounts for more than 50% percent of the total national and international haulage (tkm) in Belgium, Austria and Netherlands. As observed in the calculation without the consideration of passing traffic, Belgium and Netherlands' development level are much higher than other country. Therefore it is necessity to consider this part of the traffic and improve the international comparison at country level.

4.2 Apply Gravity Model in traffic formation

The gravity model is widely used aggregated model for long-distance travel demand estimation and distribution(Anderson 2010; Horowitz 2008; Xiong and Zhang 2013; Zhang et al. 2012). It is suitable to apply gravity model here when we discuss the OD traffic flow relationship with two regions. We use the general format of gravity model; and basic formats of trip generation $f(G_i)$, attraction $f(A_j)$and distance facto $f(r)$; and further exam the contribution of the factors of GDP, Population to the trip generation and attraction.

$$T_{ij} \propto f(G_i)f(A_j)f(r_{ij}) \quad (4.1)$$

The data in this part includes region to region transport demand in Japan (Passenger), US (Freight) and EU (Passenger rail), which will be introduced in detail in the following sections.

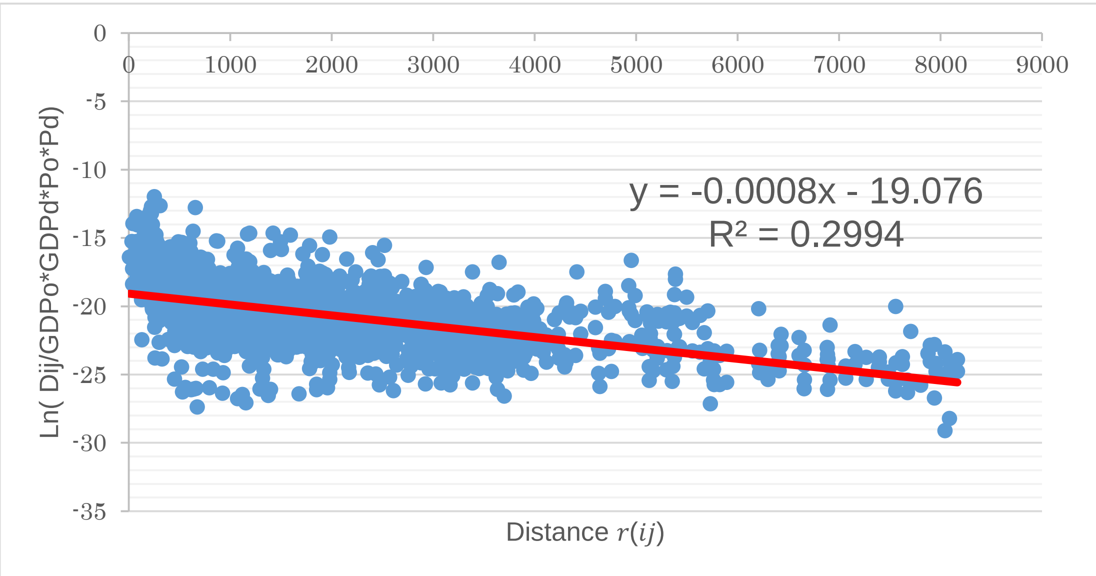
4.2.1 Parameter estimation of passing traffic of domestic transport

In order to estimate the contribution of the factors of GDP, Population of Origination and Destination to the trip generation and attraction. I firstly use the expression of (4.2) to exam the contributions.

$$D_{ij} = \frac{GDP_o^{\alpha_o} GDP_d^{\alpha_d} P_0^{\beta_o} P_d^{\beta_o}}{f(r_{ij})} \text{ , } f(r_{ij}) = \exp(-ar_{mn}) \quad (4.2)$$

In addition to Japan's regional data, I use US freight OD data obtained from USDOT to conduct multi-regression analysis. The data is compiled from various national statistic sources. The results are showing as following:

$$y = -0.0008x - 19.076 \qquad R^2 = 0.2994 \quad (4.3)$$



The detailed test results are listed in *Annex 1 table 1*

Figure 14 Regression results 1 (Source: author)

Secondly, I tried use another express (4.3) of the distance relationship to conduct regression analysis.

$$D_{ij} = \frac{GDP_o^{\alpha_o} GDP_d^{\alpha_d} P_o^{\beta_o} P_d^{\beta_o}}{f(r_{ij})} \ , f(r_{ij}) = r^{\varepsilon} \qquad (4.4)$$

The results are shown in (4.5). The detailed test results are shown in *Annex 1 table 2*

$$y = -1.564\ln(x) - 9.2335 \qquad R^2 = 0.382 \qquad (4.5)$$

4.2.2 Parameter estimation of passing traffic of international transport

EU Railway data set from EU statistic year books is used to exam the parameters of the gravity model for international traffic. The data is compiled from EU statistic on transport development. The distance between each OD pair is calculated using google map.

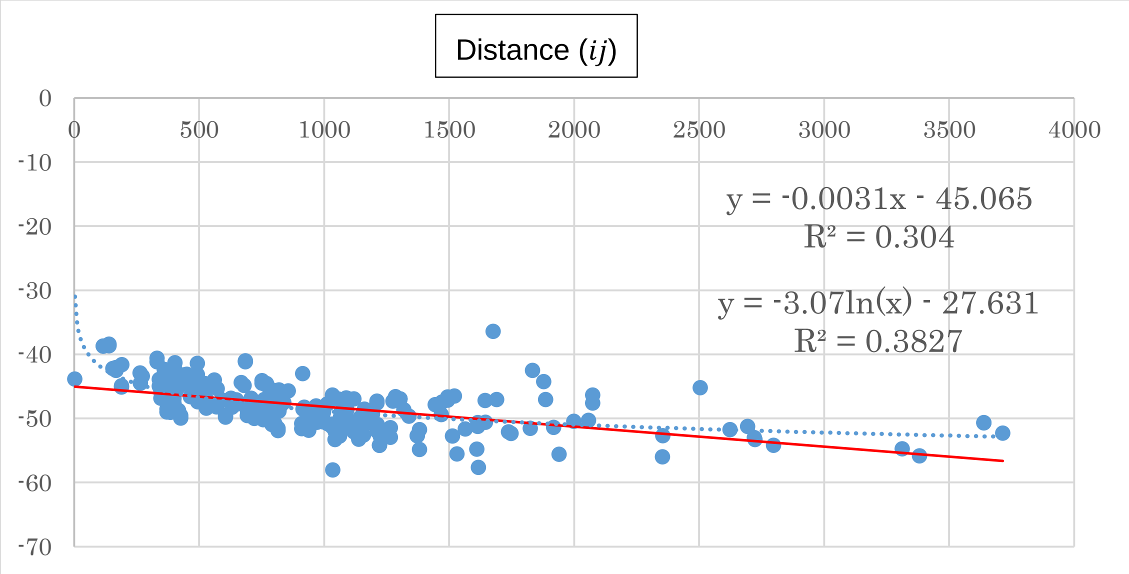


Figure 15 Regression result using data of EU Railway of OD of International rail traffic

The results from using expression (4.2) are described as (4.6). The detailed test are presented in *Annex 1 table 3.*

$$y = -0.0031x - 45.065 \qquad R^2 = 0.304 \qquad (4.6)$$

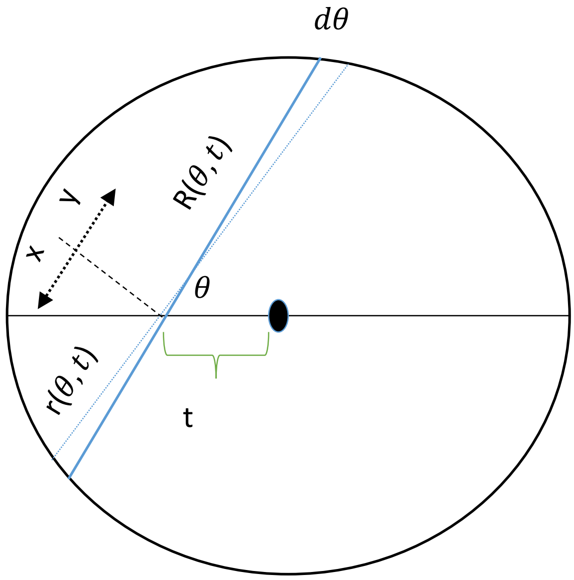
The results from using expression (4.4) are described as (4.7). The detailed test are presented in *Annex 1 table 4.*

$$y = -3.07\ln(x) - 27.631 \qquad R^2 = 0.3827 \qquad (4.7)$$

4.3 Attempts to simplify geographic impact on through traffic

4.3.1 Generalized Geo-location and passing traffic relationship I

Here we would like to propose a generalized solution to reflect the geo-location and the passing traffic relationship.



If we simply the country into cycle shape instead of square shape. t denotes the distance from the center of cycle to the any point. Assume the population and GDP is evenly distributed. We use the case of population and GDP all equal to 1 unit at any point to form the passing traffic calculation. If the distance factor in gravity model are $f(r_{ij})$

$f(r_{ij})$= $\exp(-ar_{mn})$

Then the passing traffic at point i_t denotes to $f(T_{i_t})$ can be calculate as following:

$$f(T_{i_t}) = \int_0^{2\pi}\int_{x=0}^{r(\theta,t)}\int_{y=0}^{R(\theta,t)} e^{-a(x+y)}xydxdyd\theta = \int_0^{2\pi}\frac{(ar-e^{ar}+1)(aR-e^{aR}+1)e^{-a(r+R)}}{b^4}d\theta$$

(4.8)

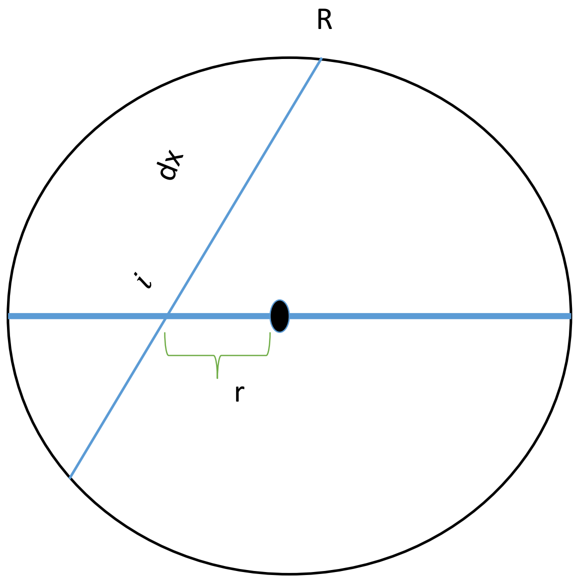
Where

$$R(\theta,t) = \sqrt{R^2 - t^2\sin\theta\sin\theta} + t\cos\theta \quad (4.9)$$

$$r(\theta,t) = \sqrt{R^2 - t^2\sin\theta\sin\theta} - t\cos\theta \quad (4.10)$$

However, due to the complex of the integral. It is difficult to solve it by hands. In the next step numerical solution will be generated using software. On the other hand another solution is provided in section 4.2.3

4.2.3 Generalized Geo-location and passing traffic relationship with simplification II



For any point i, the passing traffic at point i_r denotes to $f(_{T_{i_r}})$; $f(_{T_{i_{rij}}})$ denotes the sum of intra-regional traffic T_{ii}, and the traffic from the region i to other regions $\sum_j T_{ij}$, the traffic from other regions to region i , $\sum_j T_{ji}$

If the distance factor in gravity model are

$$f(r_{ij}) = (\frac{1}{r})^{\alpha} \tag{4.11}$$

R is radius of the cycle.

Then $f(_{T_{i_r}}) \propto f(_{T_{i_{rij}}}) \propto (\int_0^{R+r} x \cdot (\frac{1}{x})^{\alpha}\, dx)(\int_0^{R-r} x \cdot (\frac{1}{x})^{\alpha}\, dx)$ (4.12)

If let the $\alpha = 1$ in (4.11), then the distance relationship simply to $f(r_{ij}) = \frac{1}{r}$

(4.12) accordingly simply to

$$f(_{T_{i_r}}) \propto f(_{T_{i_{rij}}}) \propto (\int_0^{R+r} x \cdot (\frac{1}{x})\quad dx)\,(\int_0^{R-r} x \cdot (\frac{1}{x})\quad dx) = R^2 - r^2 \tag{4.13}$$

In conclusion, then here is a simplified relationship between passing traffic and the geolocation of the region: $f(_{T_{i_r}}) = \mu(R^2 - r^2)$ $\mu\ is\ consitant$ (4.14)

Chapter 5 Application and Policy Analysis of the NDL to International Comparison

In this chapter, the method developed and Normalized Development Level index will be applied to international comparison of expressway, railway, HSR, airport across countries followed by policy discussions. It provides the development level comparisons and comparative trend from 1960 to present among around 15 countries. In the later part of this chapter, the Integrated Normalized Development Level for all modes will be presented, which provides an integrated overview for the inter-regional transport infrastructure development level. **It presents i) the integrated development level comparisons for all modes; ii) NDL of each mode individually; and more importantly iii) the development patterns of every country in terms of modes.**

Section 5.1 presents the development level comparison of expressway from 1960 to present for 14 countries. Section 5.2 provides the development level comparison of HSR from 1960 to 2014. Section 5.3 presents the development level comparison of airport in both accessibility and capacity assessment. Section 5.4 provide the preliminary results of development level comparison of railway. Section 5.5 dedicated to the results of integrated development level comparison covering all modes. It reveals the development pattern of each countries towards different modes. Data descriptions are provided for each mode.

5.1 International Comparison of expressway from 1960 to present

Expressway has been the basic predominate mode for faster inter-regional connectivity in most of the countries before the introduction of HSR and the rapid growth of airline industry. This research improved the through traffic calculation and updated the data to 2014 at the country level comparison. The updated expressway data are compiled from World Bank databank, EU statistic, Japan national statistic and China statistic yearbook. The detailed data inputs will be described in Annex 3.

5.1.1 Expressway Development Level from 1960-2014

The following graph shown the results of the applying the improved model with consideration of passing traffic at the country level comparison.

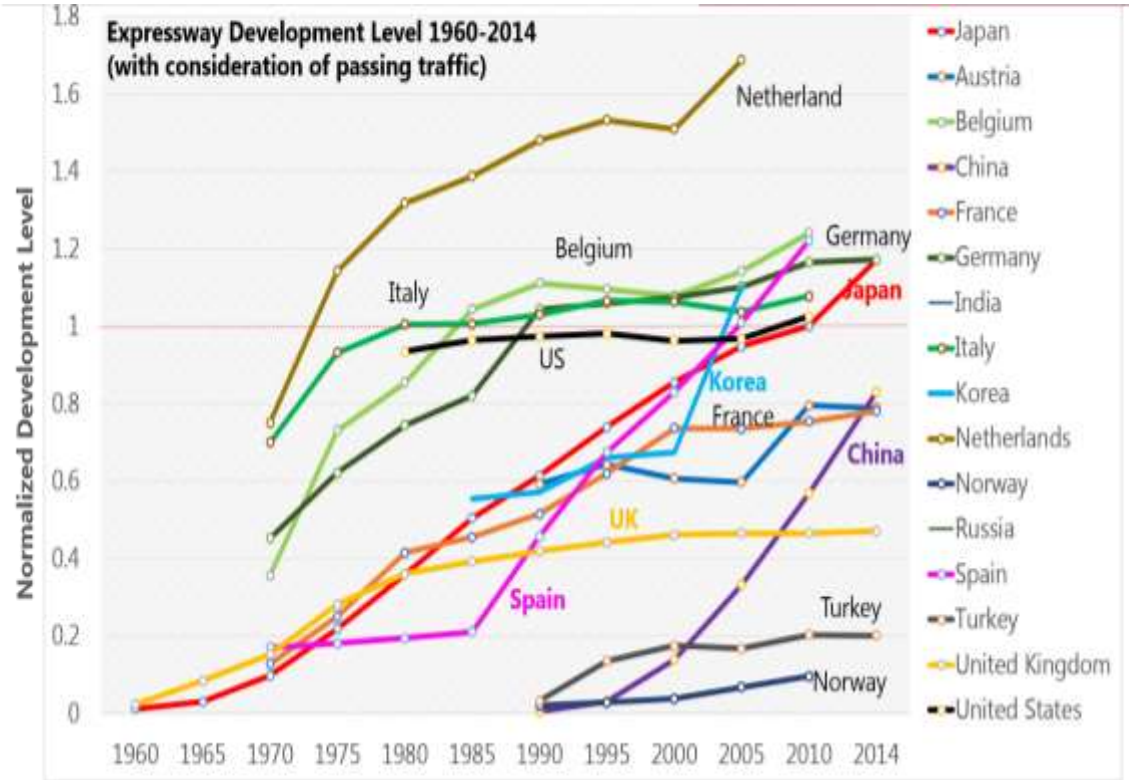


Figure 16 Expressway Development Level 1960-2014 (Base line 1 is Japan National 2005 Level)

In this assessment result, the base line 1 is Japan National 2005 Level. It means that all other countries are compared to Japan National 2005 Level. As introduced before, Normalized Development Level as r_α :

$$r_\alpha \equiv \frac{\alpha}{\alpha_0} = \frac{\frac{S}{N^*}}{\frac{S_0}{N_0^*}}$$

Then, in this assessment, S_0 is the expressway supply of Japan in the year of 2005. N_0 is the necessity of Japan in the year of 2005. We are also able to observe how Japan developed the expressway toward current level from 1960.

General trend: within the countries in this comparison, Netherland has the highest development level. The second group is Italy, Belgium, Germany and US. They enjoyed higher level of development since 1970s. And the development level keep stable which is closed to 1 from 1980s. Japan, France and UK have similar development pattern from 1960s, after 1980s France and UK lower down the development level.

Figure 17 Netherlands National Highway Plan 1968 (Source: Wikipedia)

Regarding the Netherlands, the rationale of the comparatively high level of development, is partially because of its transport and logistic sector has been playing key role in its economy as the direct contributor, while transport infrastructure built by most of other countries are mainly for the indirect contribution to economy growth. Similar approach can be observed in Singapore’s port and airport development. In the EU, the trend of slowing down the development after 1975s can be interpreted as the reflections on the oil dependency.

Figure 18 Netherlands National Highway Plan 1984 (Source: Wikipedia)

As the oil crisis occurred in the mid-1970s, the Netherlands revised its expressway development master plans into various versions with lower density comparing with the version before the oil crisis. Other EU countries also share similar development pace, which is slowed down after 1975s. Another reason is many countries in the EU started to shift the focus of regional development to metropolitan development after 1980s.

Spain started the sharp increase from around 1985. It partly benefit from EU policy and funding supports. Spain joined EU from 1986 and has been benefit a lot of EU's strategy of connecting west to east policy as well various funds for this kind purpose. As Spain located on the west coast of EU, the improvement of Spain's expressway network will also contribute to the logistic improvement of EU.

Within the EU countries, Norway is obvious taking a different approaches in the expressway development. The development level of expressway in Norway is lowest among EU countries and other developing countries in this comparison. It partly because Norway choose to develop other inter-regional transport mode. The multi-mode development pattern will be discussed in the integrated NDL section. As Norway has extreme weather conditions with limited inhabited area and low density. The result might also reveal an issue of the modal. In the next step, more Northern Europe country will be included in the discussion.

In the developing country group, Korea already has quite high level in the year of 1985 and has a sharp increase from 2000. China begins its first expressway in 1988 after that China has been consistently increasing the development level at one of the fast speed. China catches up with other advanced region in 30 years. As shown in the map below, it is the China's expressway Master Plan 2005-2030, however China has completed 70% of it in 2007 and further speed up the construction in 2009 in order to stimulate the economy against the global economy crisis. Similar as China, the sharp jump of Korea might be also related to the Asia crisis and the stimulation package. China's rapid construction of expressway also benefit from decentralized structure and the toll collections (Reja, Amos, and Hongye 2016).

Figure 19 China Trunk Network Plan 1992-2020 (source: Ministry of Transport, China)

Figure 20 China's Expressway Master Plan 2005-2030 (Source: Ministry of Transport, China)

Turkey has moderate increase speed compared to other countries. I will discuss Turkey's approaches in other modes of transport.

5.2 International Comparison of HSR from 1960 to present

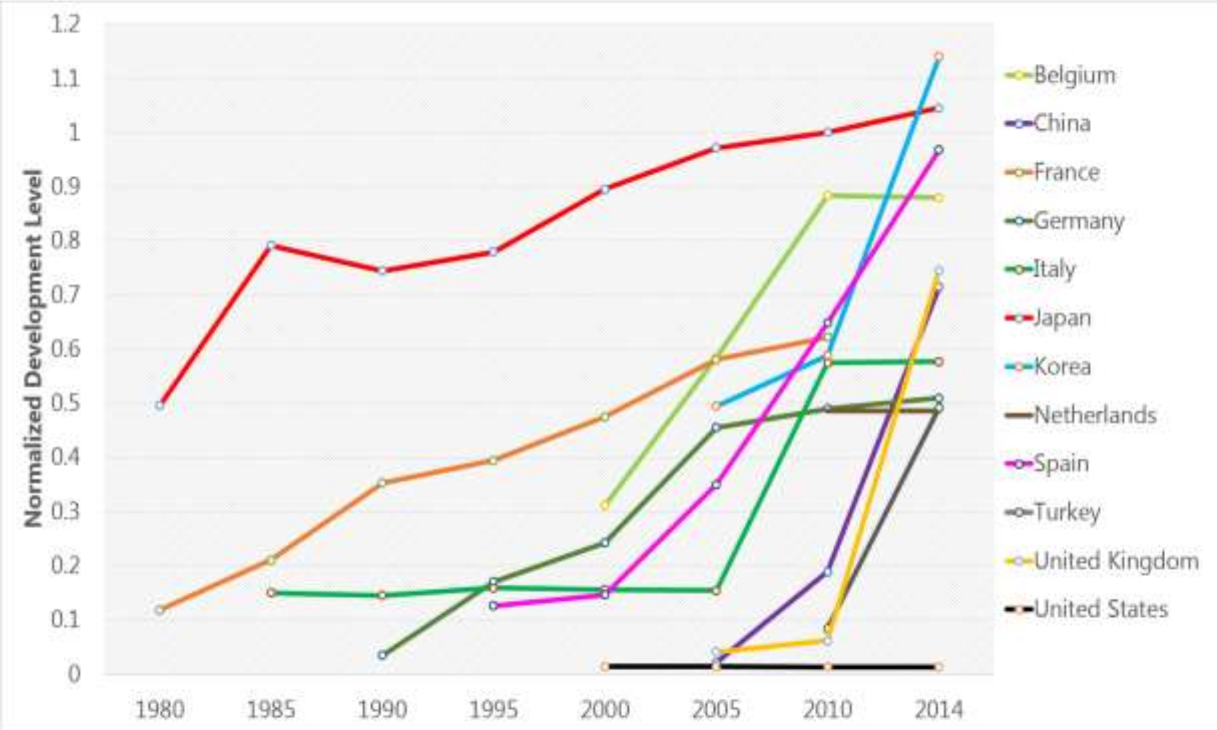


Figure 21 High-Speed Railway Development Level from 1980 to present (Source: Author)

The NDL in the accessibility perspective is applied to HSR. Japan is leading the development level from the very beginning. For Japan, France and Germany these countries which are well known for its HSR technology and development, they have higher NDL until 2005. Surpassed by Belgium, Spain, Korea and China.

Notably, Korea, Spain and China are increasing at very fast speed. In Spain's case, its development has been benefit from Trans-Europe network development in these 20 year. Most of the priority project of TEN-T are railway and HSR projects aiming at enhancing the connectivity between west and east. (Infrastrcuture-TEN-T-Connecting Europe Priority projects 2014) There are several large scale ongoing HSR projects aiming at connecting the "old and new member countries". China has built up the longest network in recent 10 years. However as the necessity of HSR is large, then the NDL is still not the highest.

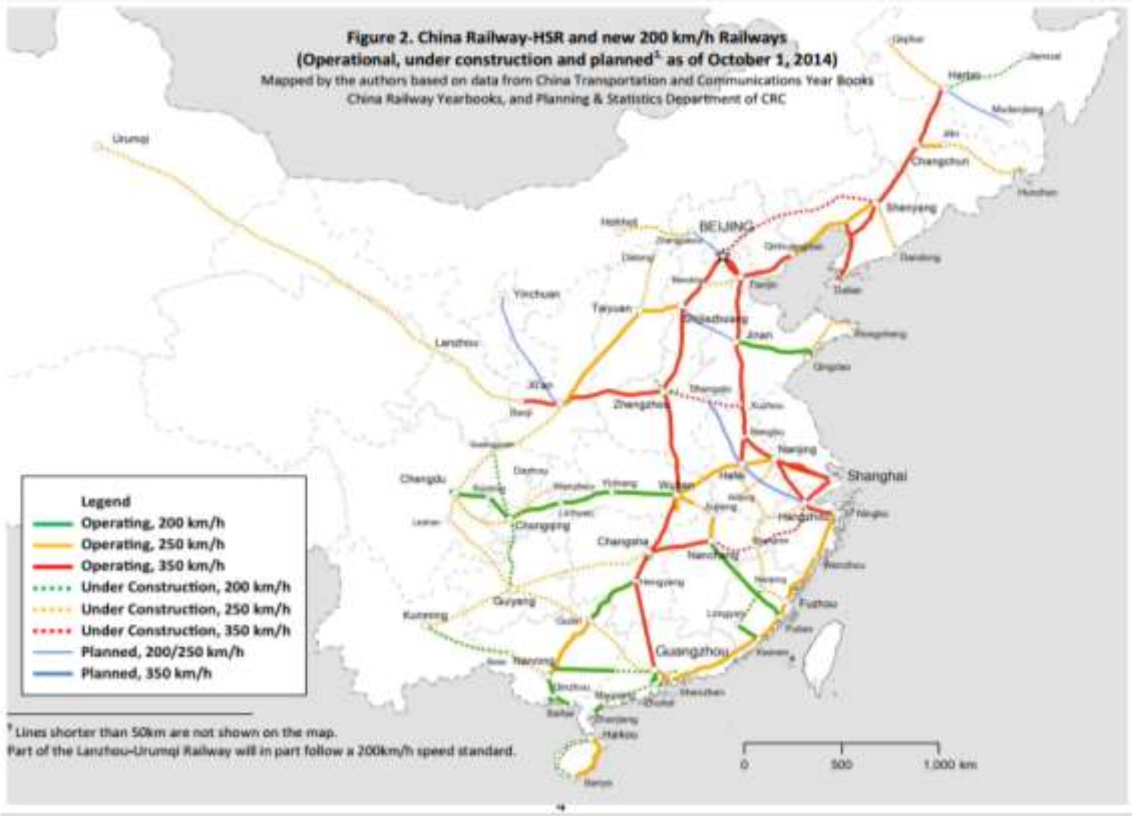


Figure 22 China HSR Map

Source: World Bank Report (Ollivier, Sondhi, and Zhou 2014)

The map presented the HSR network in China in the year of 2014. The left figure shows the HSR network length, comparing China, Japan with other countries in the rest of the World. It again reals the nature of the NDL comparison is comparing the supply and necessity ratio with the base country.

The pattern of modes will be discussed in the integrated NDL in later section.

5.3 International Comparison of Airport from 1970 to present

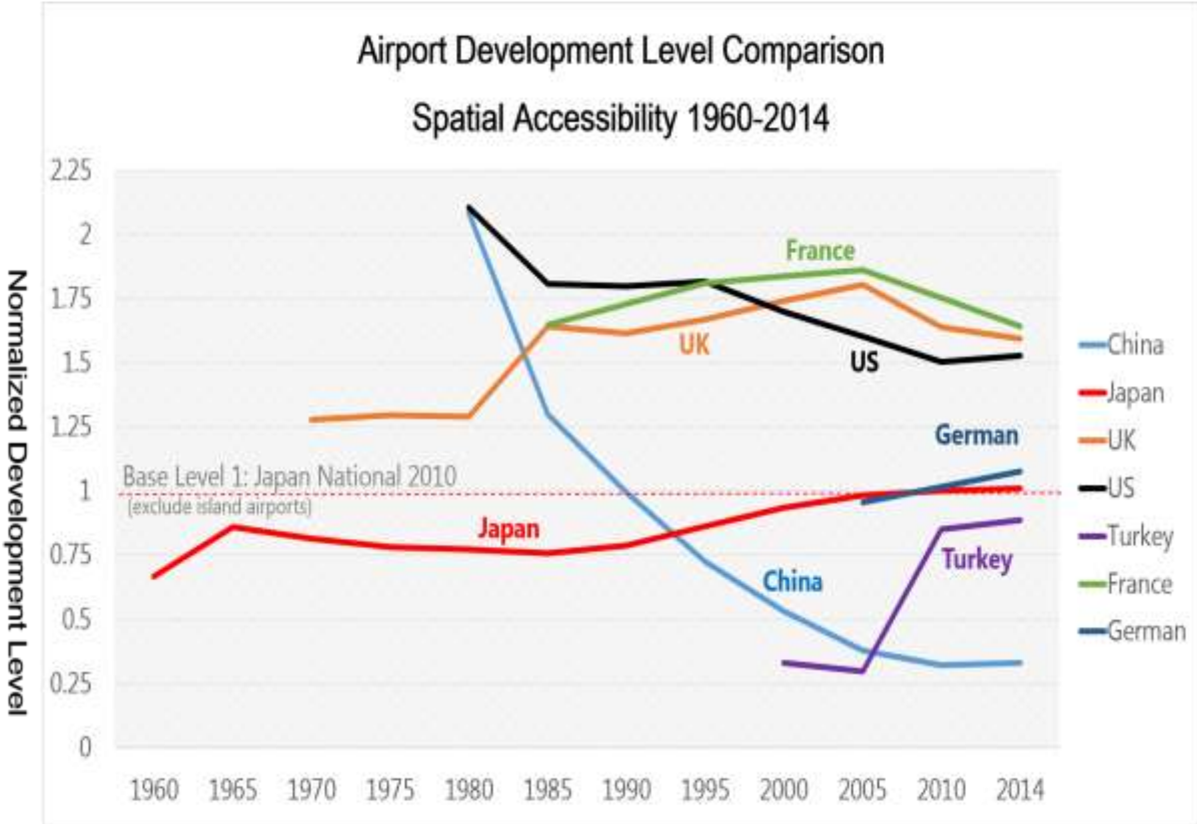


Figure 23 Airport Development Level Comparison Spatial Accessibility 1960-2014 (Source: Author)

The NDL is applied to Airport Development Level Comparison in time series from 1960 to 2014. Compared to Japan, UK, US and France's development are higher than Japan. The detailed discussion of airport development in Japan, UK , France will be carried out in Chapter 6. It is interesting to note that China decrease sharply, although in the fact that China has constructed around 100 new airports in the past 30 years. The detailed development in China will be discussed in the Chapter 6. In the contrast, Turkey as another developing country, the development trend is increasing sharply. It indicates that Turkey is taking more aggressive approach toward airport development than expressway. From literature review that Turkey's civil aviation demands in terms of passengers has been increased a lot in the past decades(Management 2013), the assessment of NDL shows that the supply of infrastructure is also in the pace to accommodate the demand.

5.4 International Comparison of All modes

I integrated the NDL for expressway, HSR and Airport, using the triangle to represent the mode pattern and the integrated development level suggested by the size of the triangle. Each mode at the certain year is compared with the base line year of national NDL 1 of Japan.

The patterns are very interesting. Firstly, we comparing the shape the triangle which indicating national "mode choice" or the development outcome. Spain's approaches toward the development of all modes is similar with Japan in terms of overall size and the value in each mode. Several countries are more pro expressway development, namely Italy, Belgium and Netherlands. Then the next group is the countries which has

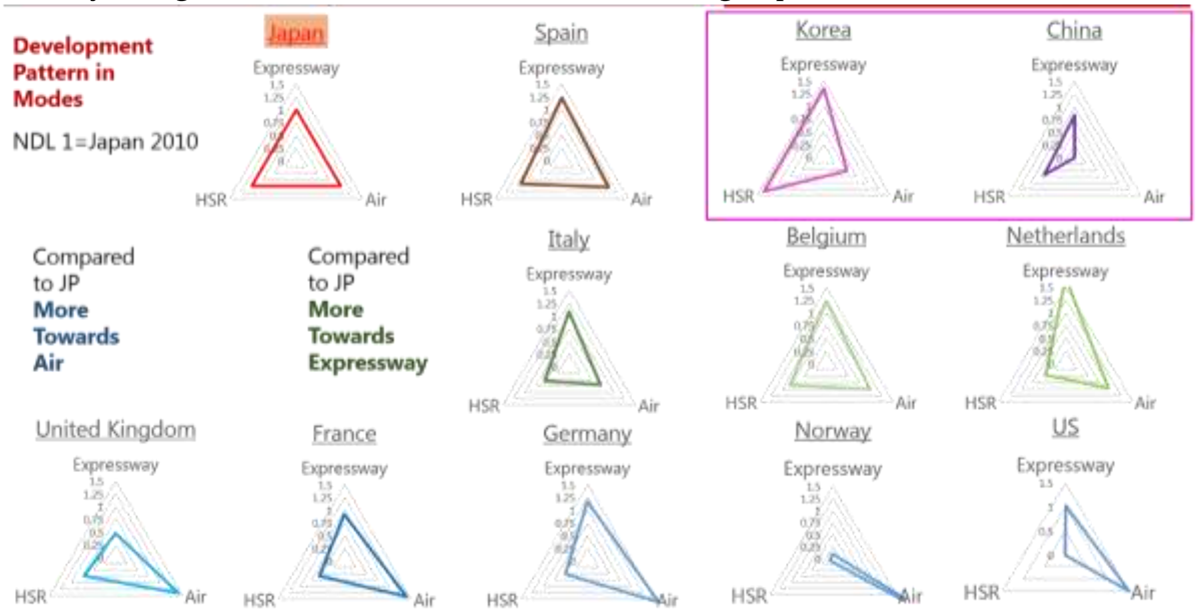


Figure 24 Modes Pattern (Source: Author)

comparably higher level in Airports than in other modes. They are UK, France, Germany, Norway and US. Norway is much relay on the airport infrastructure in the inter-reginal development. We will reveal the pattern in details later. One more interesting pattern is that Korea and China are both developed towards Expressway and HSR. It may indicate these countries has made wise decision toward the energy efficient mode.

In terms of overall integrated development level, Japan, Germany, Korea, US and Belgium have the highest level. We use the following figure to show the mode pattern as well as the overall integrated development level with horizontal axis of population density. Lower density countries have the pattern more towards airport development with the only exception, China.

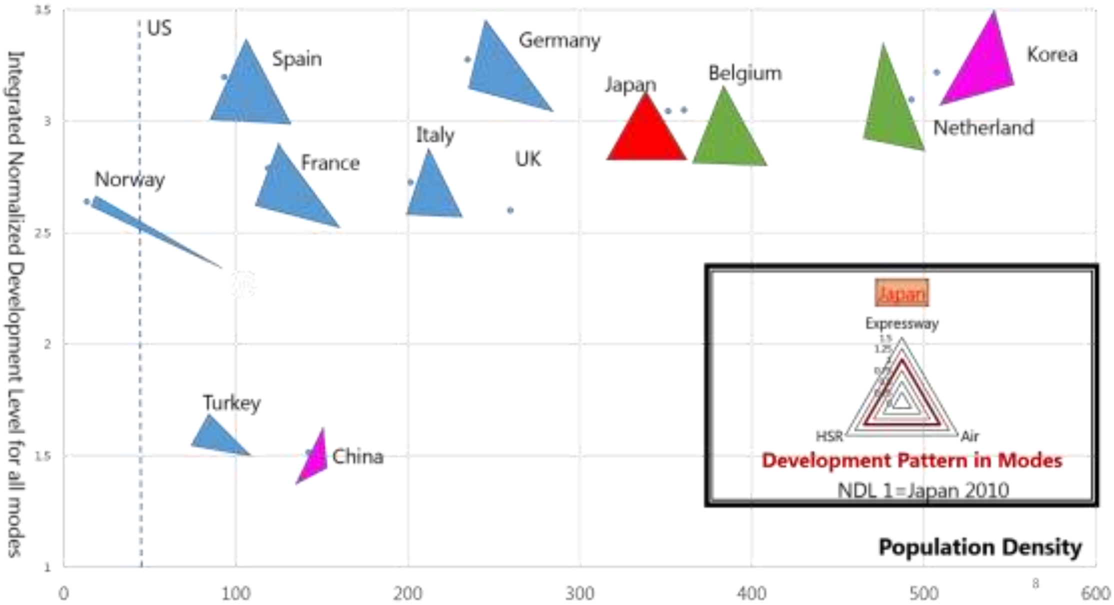


Figure 25 Modes Pattern and Population Density (Source: Author)

In sum, the method is able to make integrated assessment on all modes. It fills the blank research area of integrated assessment on all modes. Development patterns on different kinds of modes can be identified.

Chapter 6 Application and Policy Analysis of the NDL to Regional Development Comparison

In this chapter, the method developed in this research will be applied at smaller scales—the regions within a country—to exam the development level of each region across time. The comparative trend of domestic regions provides an additional view on development—the approaches toward regional development. For example, the following questions can be answered: A country is adopting a balanced approach or not. Large disparity exist or not. Focus on developing the advanced region or not. More importantly, the benefit of this method is that we can apply it to every country. Different development approaches towards regional development can be observed. Then countries can be compared and learn from each other in the issues of regional development.

I select two countries, Japan and China, to conduct the detailed regional development comparison for all transport modes. I choose Japan and China for following reasons 1) both countries have experienced the fastest economic growth in the past 100 years with similar demographic characteristic, and located in Asia; 2) Both countries have invested in transport infrastructure heavily with a comparably comprehensive master plan for national infrastructure; 3) Apply the method to one developed country and one developing country provides an illustration of the method performance.

In later part of the chapter, I focus on the discussion of airport development in several advanced country. The findings on the different development pattern provides some insights for Japan, China and other countries which are thinking of constructing new airports as well as managing the airport infrastructure and operations.

Section 6.1 presents the results of Japanese regions from 1950 to present for airport development, HSR development, expressway development. It also contains the discussion of the integrated development level comparison. Section 6.2 shows the development level comparison for Chinese regions. Section 6.3, 6.4, 6.5 and 6.6 presents the detailed analysis on the airport development level in UK, France, Korea and Japan, respectively.

6.1 Regional Development Comparison-Japan from 1950 to 2014

Japan is the country famous for its transportation infrastructure development. Before start the discussion of the regional development. I would firstly like to show the regions in Japan for form the bases of geographic understanding for the further discussion.

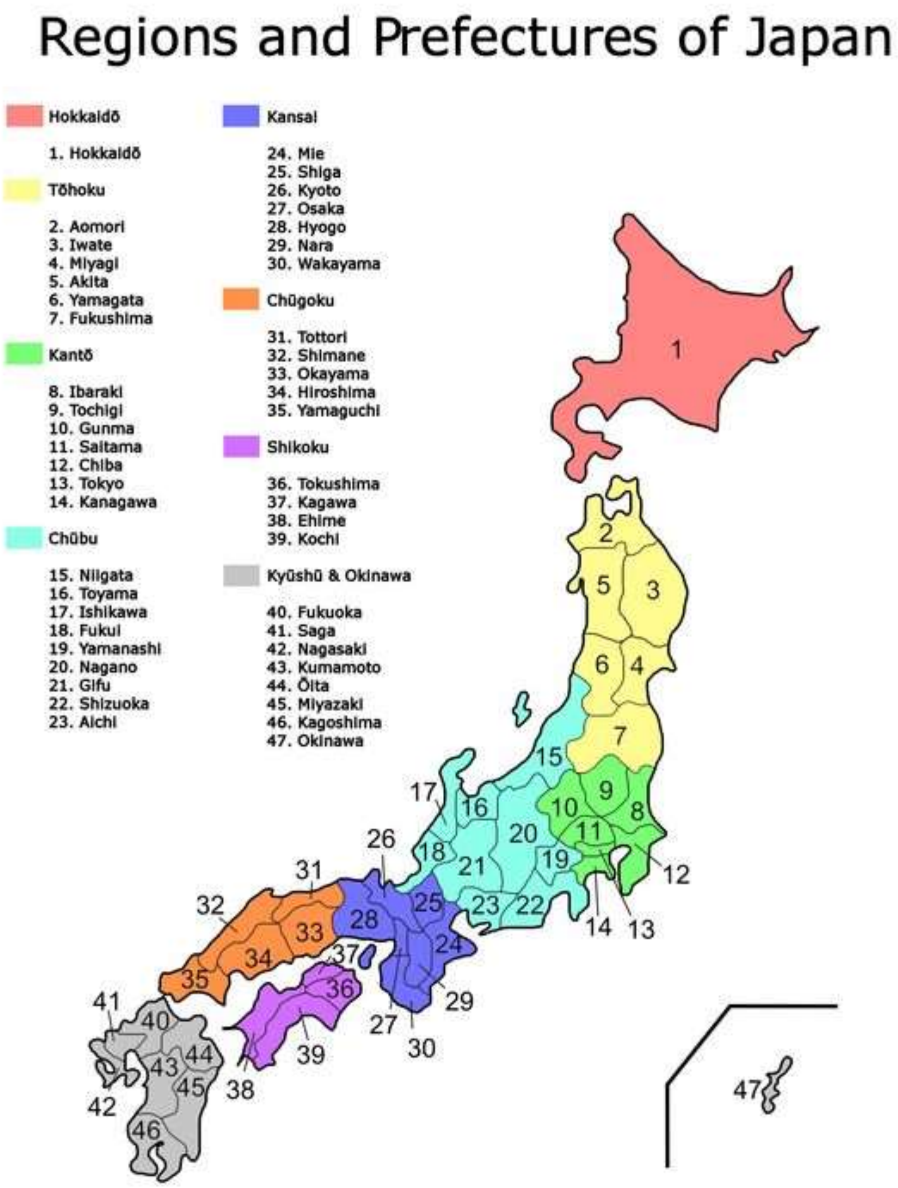
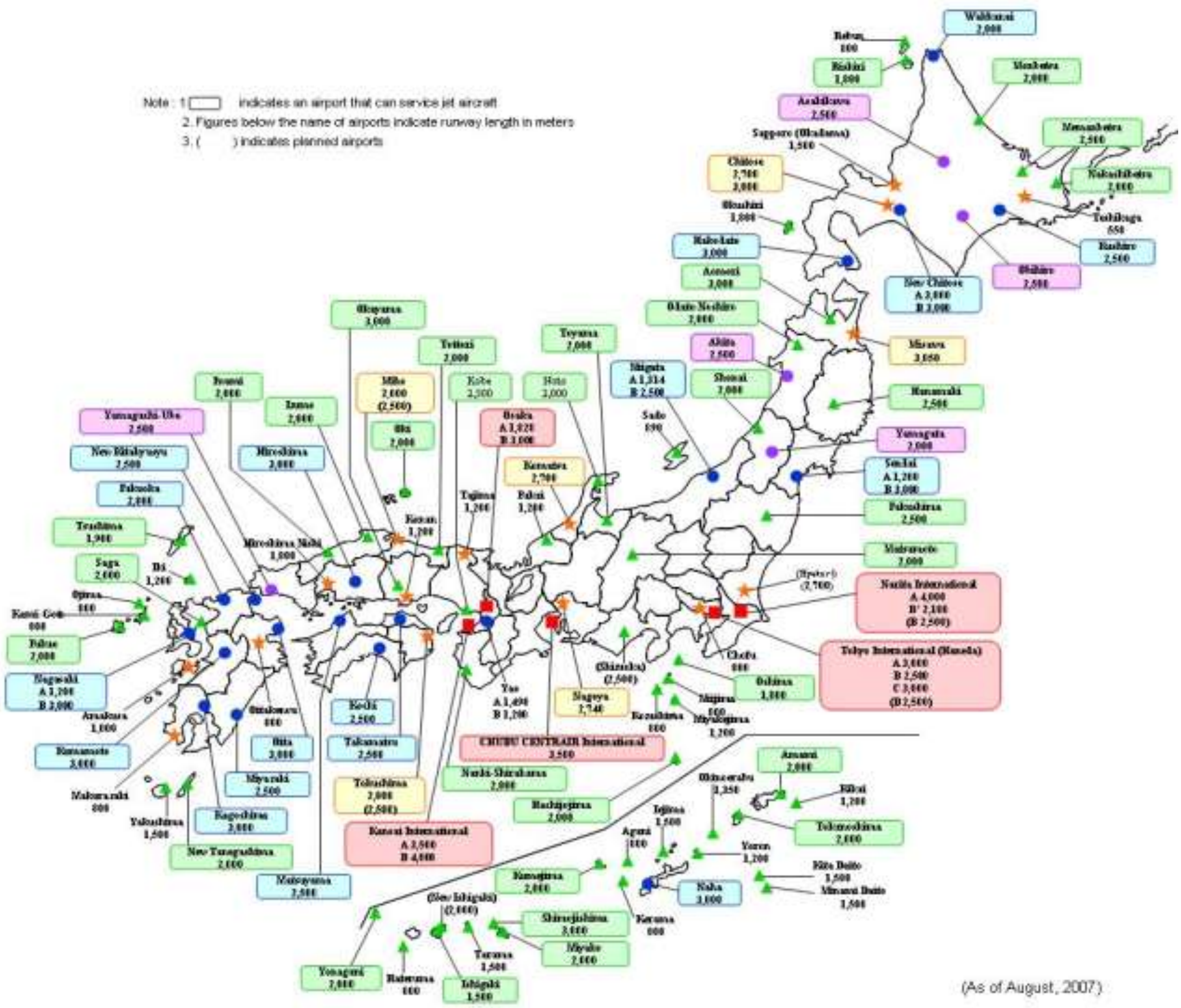


Figure 26 Figure Regions in Japan

(Source：https://jp.pinterest.com/pin/565835140654062995/)

To form the basis of our discussion, the map shows the current airports in Japan

Airports in Japan



		Airport Category	Established and Administered by	Main Role of Airports	Airports in Service	Airports for Jet Aircraft	Planned Airports
Aero-dromes	Aerodromes for Public Use	Class 1 Airport	Minister of Land, Infrastructure and Transport Narita International Airport Corporation Kansai International Airport Co. Ltd. Central Japan International Airport Co. Ltd.	Airports mainly for international air transport	5	5	0
		Class 2 (A) Airport	Minister of Land, Infrastructure and Transport	Major airports mainly for domestic air transport	19	18	0
		Class 2 (B) Airport	Local Governments		5	5	0
		Class 3 Airport	Local Governments	Local airports mainly for domestic air transport	53	32	2
		Others	(Joint-use Aerodromes) Defense Agency U.S.Air Force (Other Aerodromes) Local Governments	–	15	6	1
		Total			97	66	3
	Non-public Aerodromes						

Figure 27 Airports in Japan (Source: MILT)

Figure 28 HSR network in Japan (Source: http://www.nippon.com/en/features/h00077/)

6.1.1 Air Transport Infrastructure Development Level Comparison by Regions

Apply the method developed for airport development level comparisons into Japanese regions. The data of number of airport infrastructure has been improved by cross checking

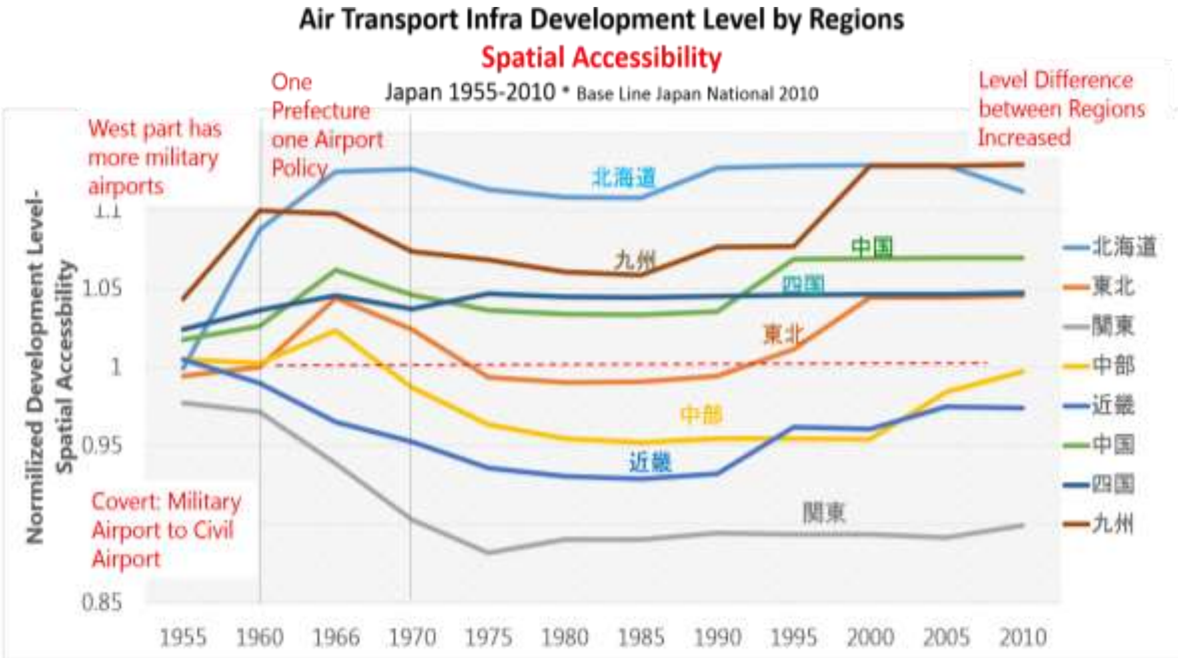


Figure 29 Air Transport Infrastructure Development Level by Regions-Spatial Accessibility (Source: author)

different sources, expanding the time period to 1955. This improvement in data is jointly done with Kani (2015). The comparison results are shown above. The base line 1 is the national average of Japan in the year of 2010. The following general trends have been observed: 1) Initial level is high; 2) The disparity between regions become larger; 3) Advanced regions' level are the lowest; 4) Regions located in the edge of the country have higher development level.

Initial level is as high as 1 which means similar to current development level. Base on the review of Kani (2015) on the historical development of military airport and civil airports, it is because after World War II many military airport converted to civil airports. As the development level in this research is compare the supply and necessity, then at the initial development stage the supply and necessity ratio is high. On one side it is because the conversion of military airport into civil airports, on another side the economic development and population is comparable small at that period. Another interesting point is that unlike expressway development which is from 0 to current level, airport develop first and distributed fast.

The disparity between regions: firstly the development higher or lower does not mean that it is better or worse, it only reflect the level compared with the base. On one side, the higher level region might be more appropriately suppled the infrastructure to accommodate the necessity. On another side that it might mean that it is over supplied. Secondly it should be noted this comparison focuses on the infrastructure provision only. The service and flight operation is not included. Then we could conclude that the investment outcome on the airport development are quite different in Japanese regions.

In the initial stages, the west regions enjoyed a big increase in the level is probably partially because west regions have more military airports than other regions based on the review of Kani (2015). In the period of the 1960s to 1970s, most of the regions' level increase a lot except Kanto and Kansai regions. In that period Japan is implementing one prefecture one airport policy. However, from my assessment this policy did not benefit Kanto and Kansai regions. On the other hand it might be the decision on the airport investment in other regions are more based on non-economic reasons, then these regions might be in the status of over supply from the beginning.

Pattern of advanced region and less-advanced region: The most advanced regions, namely Kanto and Kansai have comparably lowest development level. In in contrast that less-advanced region has higher development level. I will discuss this pattern and compare with countries in later sections of the thesis.

In terms of geographic pattern: the regions located near the boundary of the countries have comparably higher development level. As currently this is a single mode comparison, it is reasonable that some region has developed more toward a certain modes. I will compare and discuss this pattern with other countries in later sections of this thesis.

The development level in terms of resource quantity is examined as well. It provide

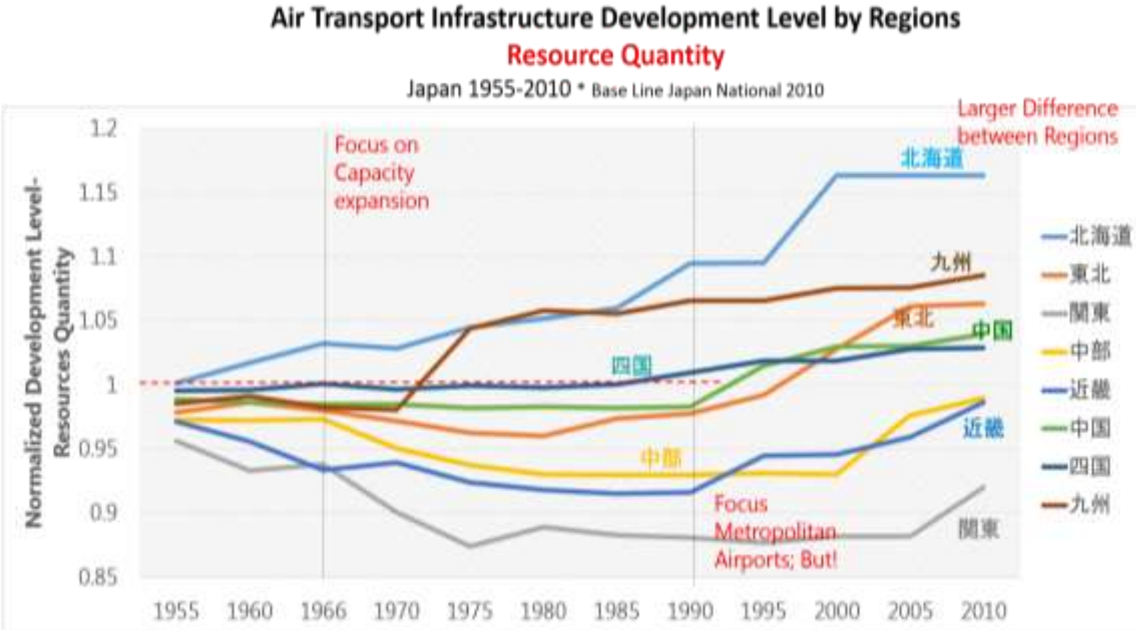


Figure 30 Air Transport Infrastructure Development Level by Regions -Resource Quantity

(Source: author)

the accessibility on both accessibility and capacity. The general trend observed in this results are 1) at the initial stage all the regions are close to 1 which is similar to the accessibility assessment; there are larger difference between regions in 2010. 2) The advanced regions are also located in the lowest.

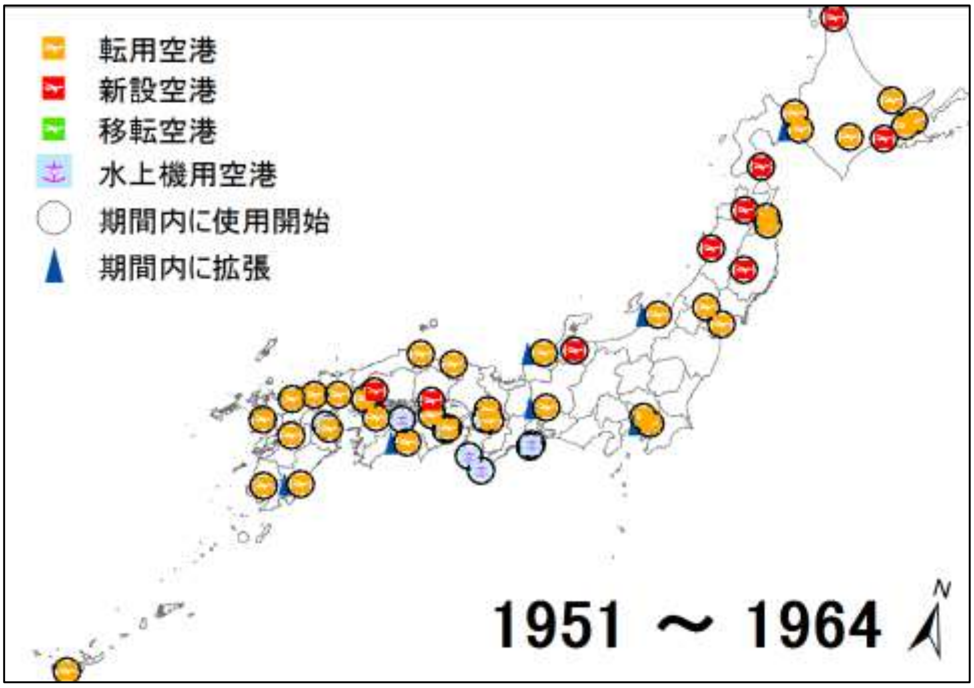
Runway Category	北海道1995	北海道2000
>3000m	2	3
3000m-2500m	2	5
2500m-1500m	5	4
1500m-914m	3	1
Under 914	1	1

Figure 31 Runway in Hokkaido

(Source: author complied from Japan Civil Aviation Year Books)

Look at the policy and investment implemented from 1966, the time the jet aircraft emerged into the market which requires longer runway. In many regions of Japan the airports enjoyed expansion in term of capacity.

To further understanding and interpreting the results. I would like to show the spatial changes of the airports (Kani 2015).



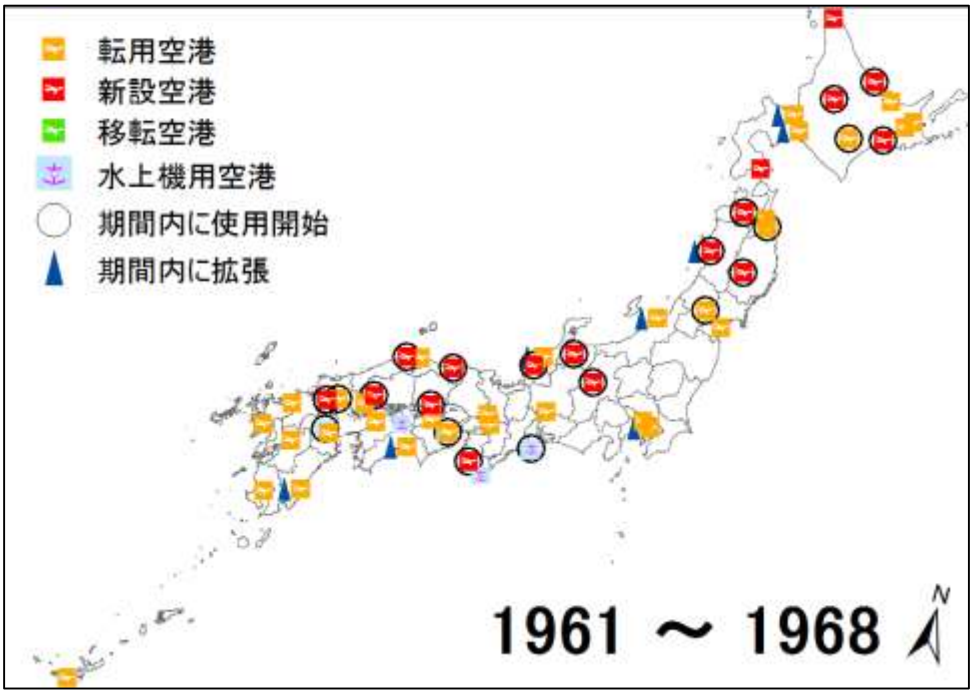


Figure 32 Airports in Japan 1951-1964 and 1961-1968 (Source: Kani 2015)

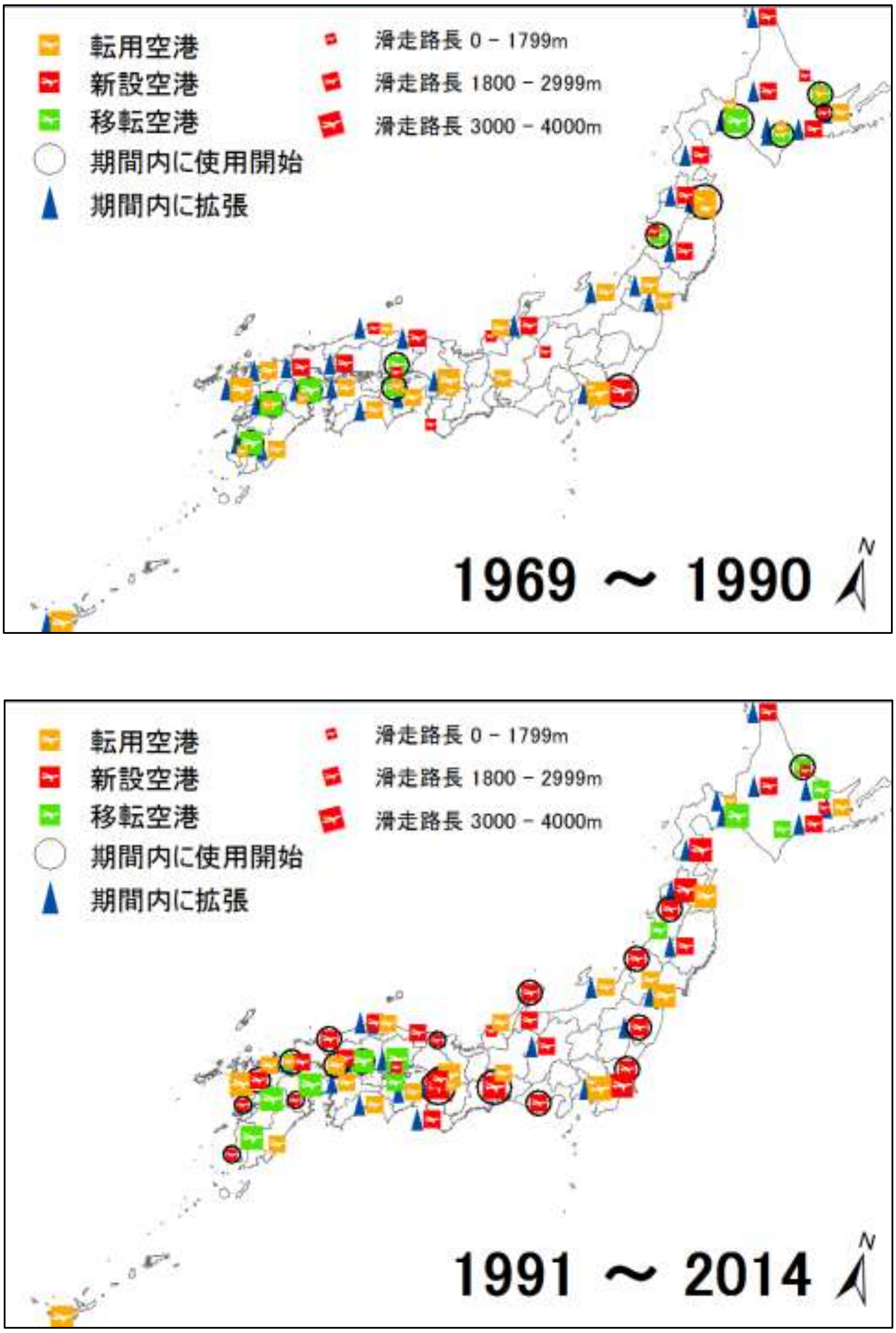
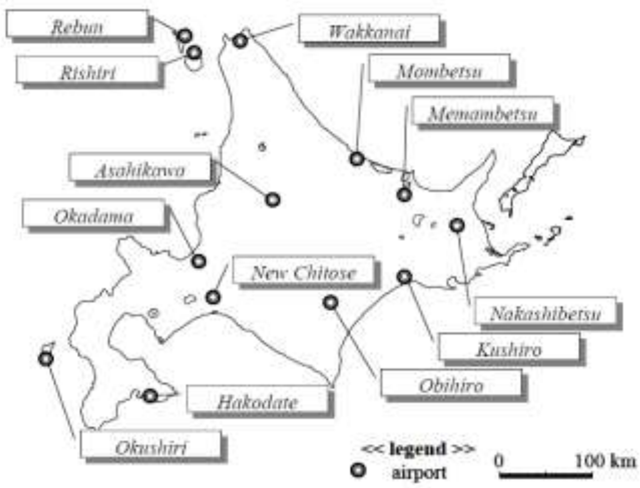


Figure 33 Airports in Japan 1969-2014 (Source: Kani 2015)

Hokkaido region increased sharply after 1990s. Several new airports are built with large capacity. However, from the policy focus of that period, Japanese government intended to focus on the metropolitan airport. In my assessment, although the level of metropolitan region improved but is as fast as other regions. I may argue that the focus of that period on the metropolitan airport development has not been fully carried out. If shift the investment from other region to metropolitan region might be wiser decision as now these metropolitan region are experiencing pressures on the capacity constraints. In the contrast, if we look at the airports in Hokkaido. Firstly, the number of airports have been increased a lot. Secondly, most of the airports are with large capacity runways. Thirdly there are 10 airports are suffering deficit in 2012 (shown in Figure 36). We may conclude that the Hokkaido region's flight operations might not operate in the way of finically sustained. Or Hokkaido region is over supply the infrastructure.

Figure 34 Airports in Hokkaido (Source from EAST website)



Large Airports in Hokkaido

Runway Category	北海道	関東
>3000m	2	2
3000m-2500m	6	6
2500m-1500m	3	0
1500m-914m	1	0
Under 914	1	1

Figure 35 compare the runway length in Hokkaido region and Kanto region

(Source: author complied from Japan Civil Aviation Year Books)

表 2　北海道内空港の航空系収支（単位：百万円）

国管理空港	新千歳	稚内	釧路	函館	丘珠（共用）
航空系収支	3675	▲764	▲424	▲703	▲357

出典：北海道 HP 2011 年度　道管理空港の空港別収支の試算結果について

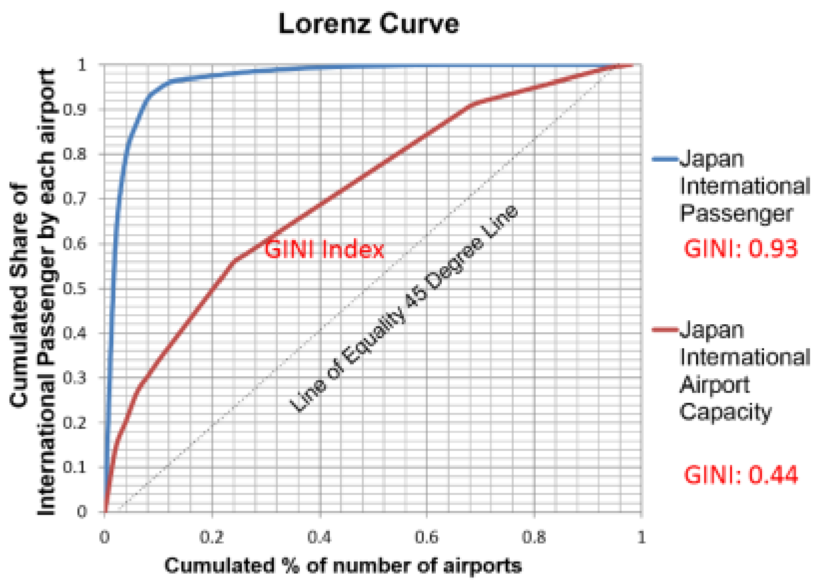
地方管理空港	女満別	中標津	紋別	奥尻	利尻	礼文
航空系収支	▲235	▲218	▲260	▲110	▲234	▲4

出典：国土交通省　2012 年度　空港別収支の試算結果について

Figure 36 Financial Performance in Hokkaido (Source: MILT)

Japan is facing capacity constrains in metropolitan airports, especially Tokyo region. However, the international passengers in Japan are concentrated in a few number of airports. I examined the concentrate level of international passengers using Lorenz Curve. The following results indicates that although the international passengers are extremely concentered in very few airport but the airport capacity are comparably evenly distributed. No matter the evaluation of capacity is based on runway or based on the spot available at the airports.　The data for Japan, and other countries is collected from Japanese Civil Aviation Statistic Year book 2013, and Airport Benchmarking Report.

Figure 37 Cumulated Share of International Passenger by each airport 2013



(Source: Author)

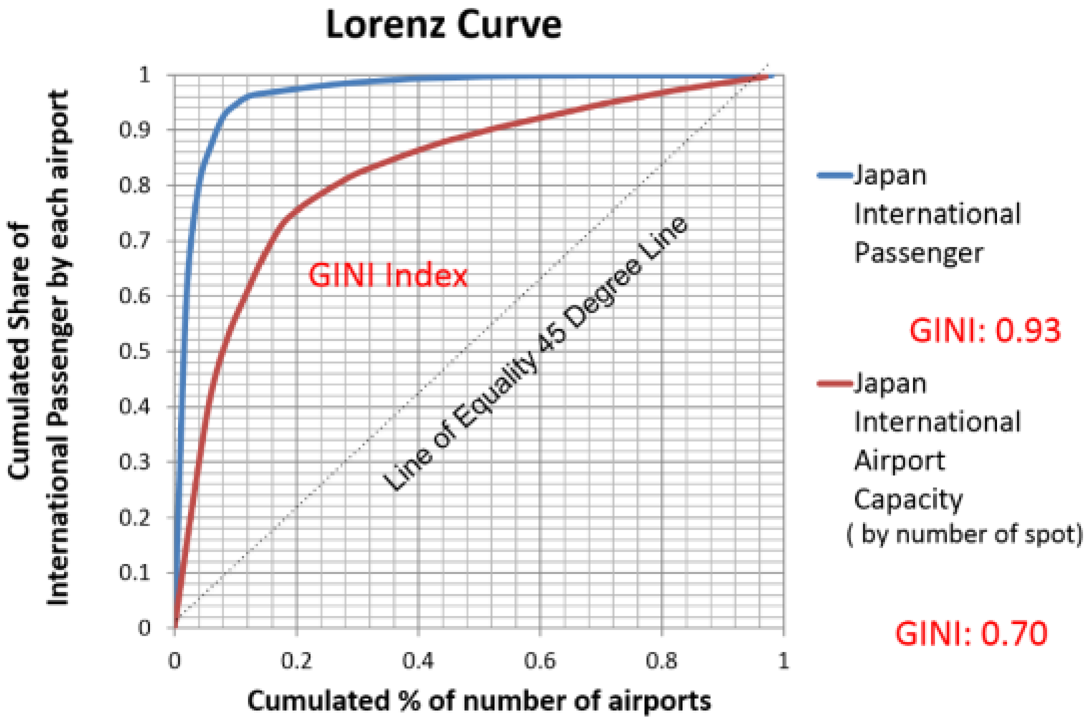


Figure 38 Cumulated Share of International Passenger by each airport (spot) in 2013

(Source: Author)

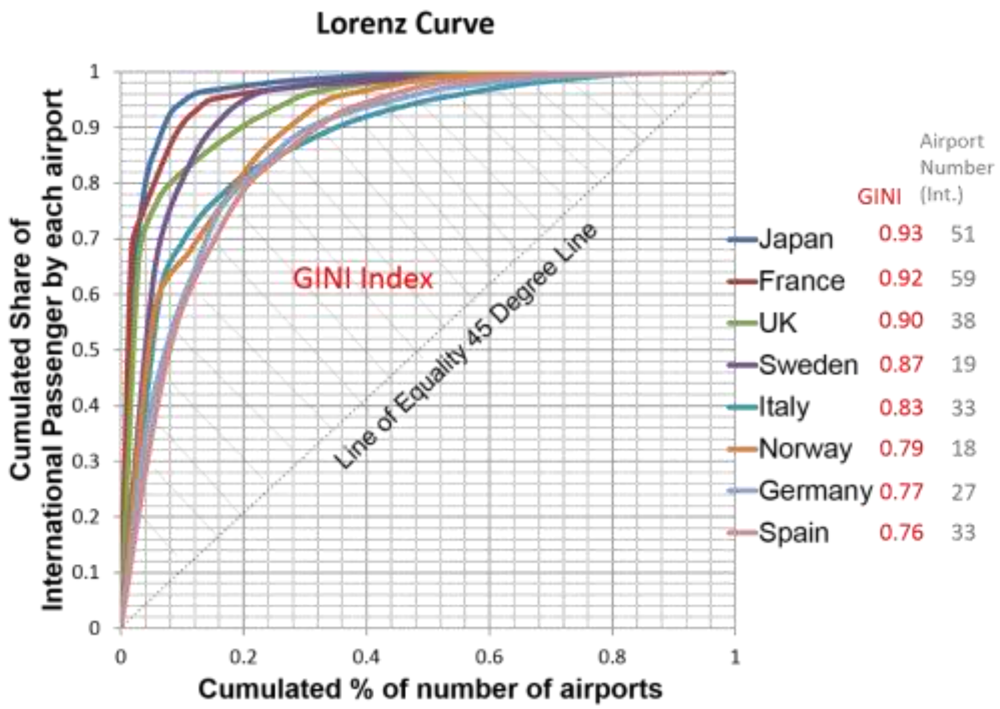


Figure 39 Lorenz Curve comparisons 2013 (Source: Author)

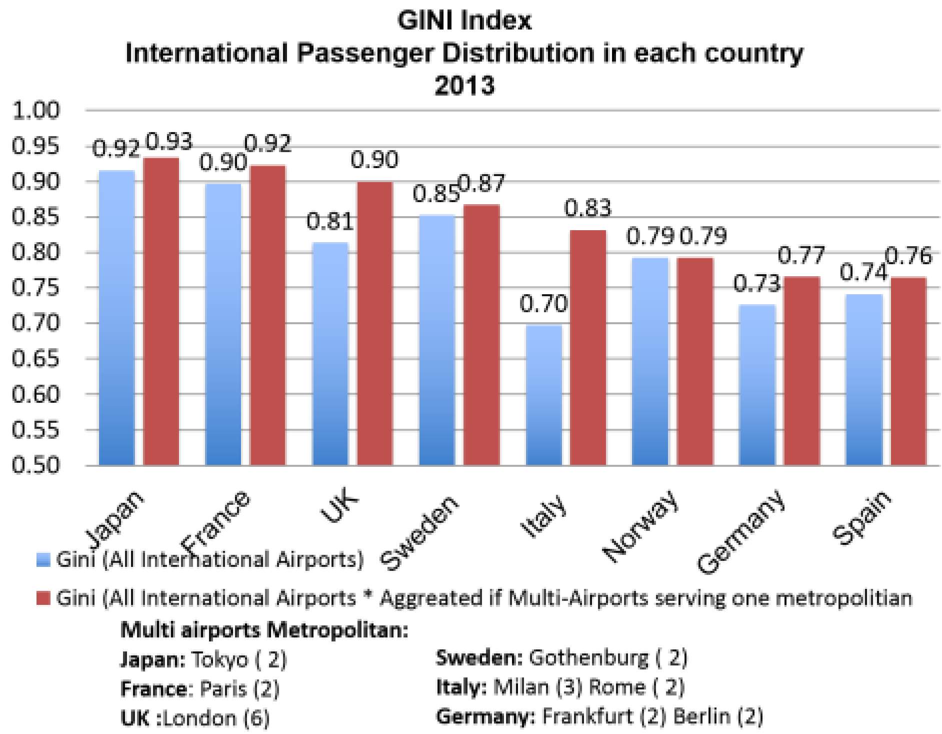


Figure 40 International Passenger Distribution in each country (Source: Author)

Compare the concentration level of international passengers with other country using Lorenz Curve, Japan showed the most concentrated level. The policy implication is that, as the several metropolitan airports facing capacity constrain issues in Japan. At the same time, it is revealed in the resources quantity development level as well as the GINI evaluation that other airport have additional capacity. Shifting the international flights to more gateway airports might be good strategy. UK has discussed utilizing the existing airports' to release London airports' pressure(CAA, 2014).

I further conducted expert interview to understand why Japan's level changes in this pattern. The findings are 1) the congestion of Tokyo airport largely impact the airline's behavior: the airline intend to use large aircraft 747 to serve domestic flight to max the utility of each landing at HND airport. Then it led to the local airport want to improve their runway in order to receive the big aircraft. Especially that the connection between Tokyo and the local airport is the most important route in order to survive. Also local airport provide subsidy to the routes. However, in reality that the 747 might not come to the local airports as often as they planned. Hence results in a large waste of capacity investment. 2) The international flights ‘impact on Tokyo region airport can be further explore to see the government’s intention on improving the hub status. UK demonstrated the determination to become the regional hub.

Regarding the point 1) , several researches have discussed the airport capacity and airline behavior on aircraft choice and frequency chances. (Takebayashi 2011) discussed the impact of runway capacity expansion at congested Haneda airport on airline choices and the social benefit of difference groups. Takebayashi also pointed out the Japan is unique in the domestic market. The airlines intend to use large aircrafts in domestic market. Several Japanese airline introduced the wide body 747 with seat capacity of 546-569 (typical capacity of B747-400 is 524) (Givoni and Rietveld 2009). Givoni shows the average number of passenger per atm at the major airports in the world. Only Haneda is using the fleet in the wide-body range, while other major airports in the world all in the narrow-body range (Shown in Figure 41) .

Table 2
Runway utilization at the world's major airports (ranked by passenger capacity, 2003).

Rank (pax)	Airport (code)	Pax (million)	Atm[a]	Rwy	Pax/atm	Atm/rwy	Pax/rwy (million)
1	Atlanta (ATL)	79.09	910,398	4	87	227,600	19.77
2	Chicago (ORD)	69.51	928,691	7	75	132,670	9.93
3	London (LHR)	64.26	460,748	2	139	230,374	32.13
4	Tokyo (HND)[b]	59.41	285,000	3	208	95,000	19.80
5	Los Angeles (LAX)	55.31	637,120	4	87	159,280	13.83
6	Dallas (DFW)	52.46	759,288	7	69	108,470	7.49
7	Frankfurt (FRA)	48.36	458,865	3	105	152,955	16.12
8	Paris (CDG)	48.12	515,025	4	93	128,756	12.03
9	Amsterdam (AMS)	39.96	392,997	5	102	78,599	7.99
10	Denver (DEN)	37.51	508,930	6	74	84,822	6.25
11	Phoenix (PHX)	36.61	544,572	3	67	181,524	12.20
12	Madrid (MAD)	35.37	382,857	3	92	127,619	11.79
13	Las Vegas (LAS)	35.34	475,420	4	74	118,855	8.83
14	Houston (IAH)	33.41	458,347	5	73	91,669	6.68
15	Minneapolis (MSP)	33.20	508,813	3	65	169,604	11.07
16	Detroit (DTW)	32.66	487,762	6	67	81,294	5.44
17	New York (JFK)	31.74	280,302	4	113	70,076	7.93
18	London (LGW)	30.06	234,248	1	128	234,248	30.06
19	Bangkok (BKK)	29.68	195,530	2	152	97,765	14.84
20	Miami (MIA)	29.53	381,248	4	77	95,312	7.38

Note: Pax-passenger, Rwy-runway.
Source: ATRS (2005).
[a] Cargo atms are included. This is not considered to considerably affect the results. In 2003, 7.2%, 4.5% and 3.7% of the atms at CDG, FRA and AMS were cargo movements. At LHR it was only 0.7%.
[b] For Tokyo Haneda the stated runway capacity and not the actual atms are used, but at this airport they are considered to be similar.

Figure 41 Runway utilization at the world's major airports (2003)
(Source: Givoni, MosheRietveld, Piet 2009)

The impact of the congestions in Tokyo region on the local airports has not been studied yet. The expert interview and the relevant researches indicates that it is worth to reveal the issues of gaps between infrastructure and operation caused by the congested hub in the nation.

6.1.2 HSR Development Level Comparison and policy analysis

The accessibility NDL is firstly apply to smaller region assessment on HSR in Japan and China. The results are shown below. The base line 1 is Japan National 2010 level. The HSR included into this research are defined as following: For new lines the design speed is above 250. For existing line, the upgraded speed is above 2000. The provinces in China are divided into 7 big regions according to classic divisions.

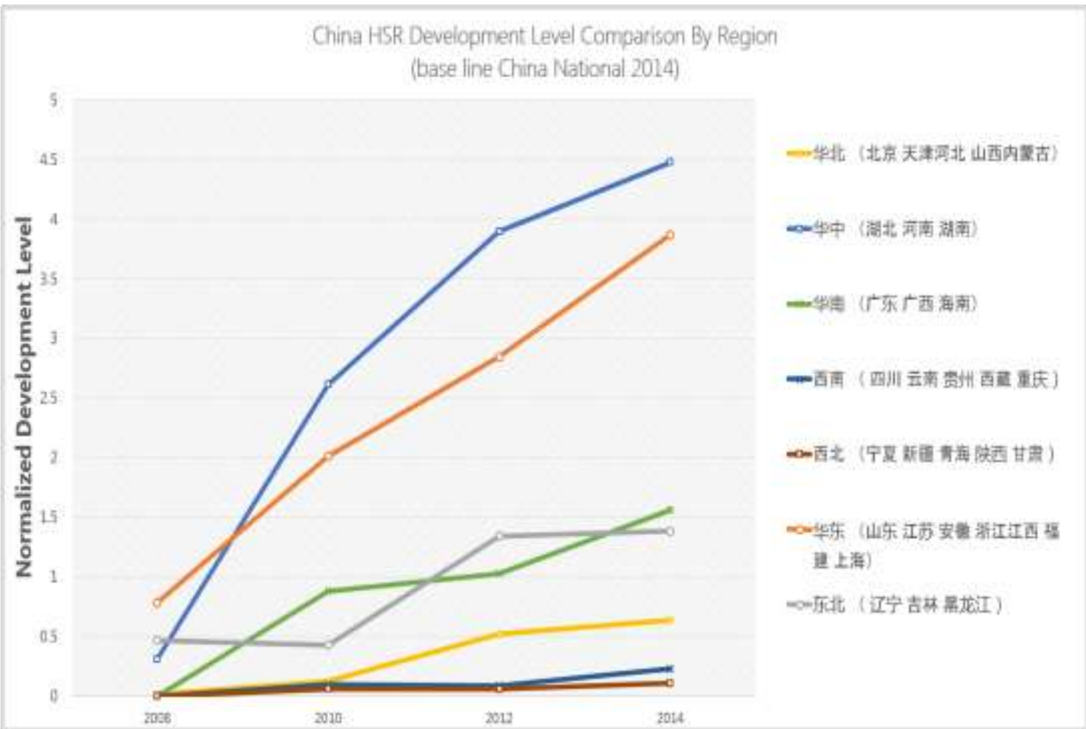


Figure 42 China HSR Development Level Comparison by region (Source: Author)

Within 10 years, China has constructed around 12000 km HSR network. Comparing the results by region, we have following findings: 1) several regions have been higher level than Japan national 2010 base line from the year 2012. 2) There is a focus on the advanced region, namely Huadong Region (including Shanghai), Huanan Region. However, considering the construction difficulty in inland regions and the line under construction.

The less developed regions will catch up with the level 1 in the near future. 3) Huazhong region enjoyed the highest level of development partly because it's strategic location, in the middle connecting north and south, west and east. 4) The development pattern is similar to Japan's HSR development pattern shown in figure 22.

Figure 43 Seven big regions in China (Source: from the internet)

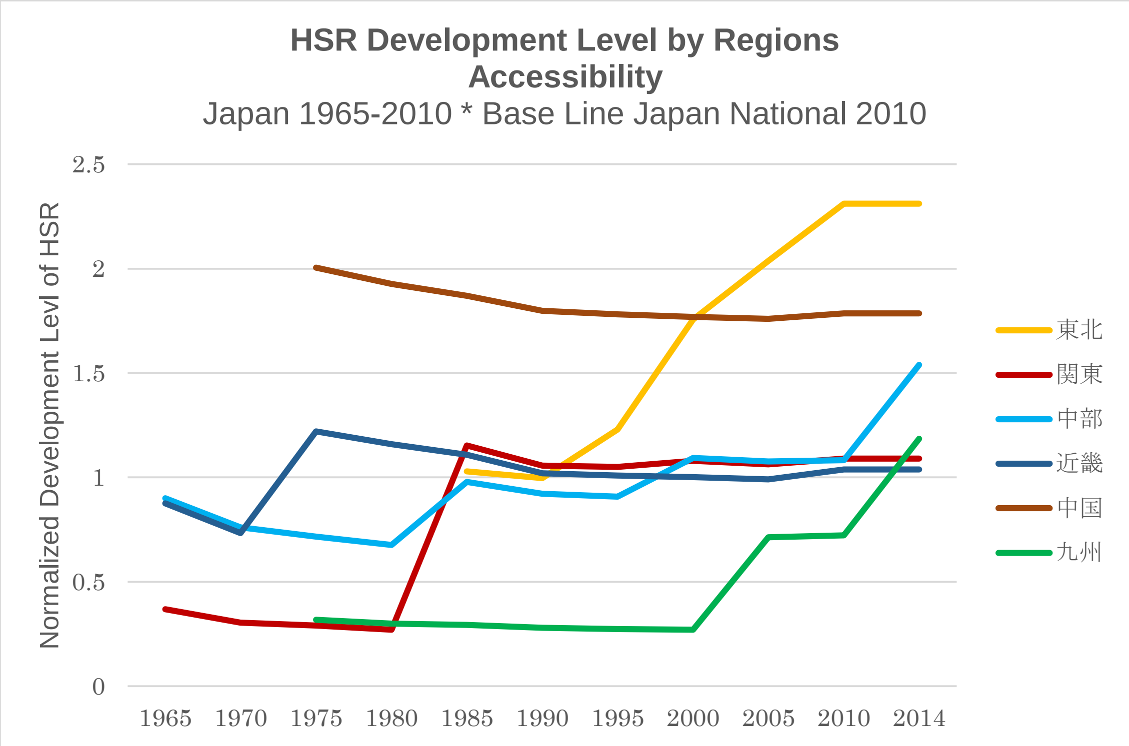


Figure 44 Japan HSR Development Level by Regions (Source: Author)

The development of HSR started from the advanced regions, namely Kanto and Kansai as well as Kinki. Later other regions catch up with the advanced region. The Chugoku region enjoyed high development level, partly because its location, which plays the role of connecting west and east. Here I will left the discussion first, and will focus on the integrated NDL for all modes in later 6.1.4 section.

6.1.3 Expressway Development Level Comparison and policy analysis

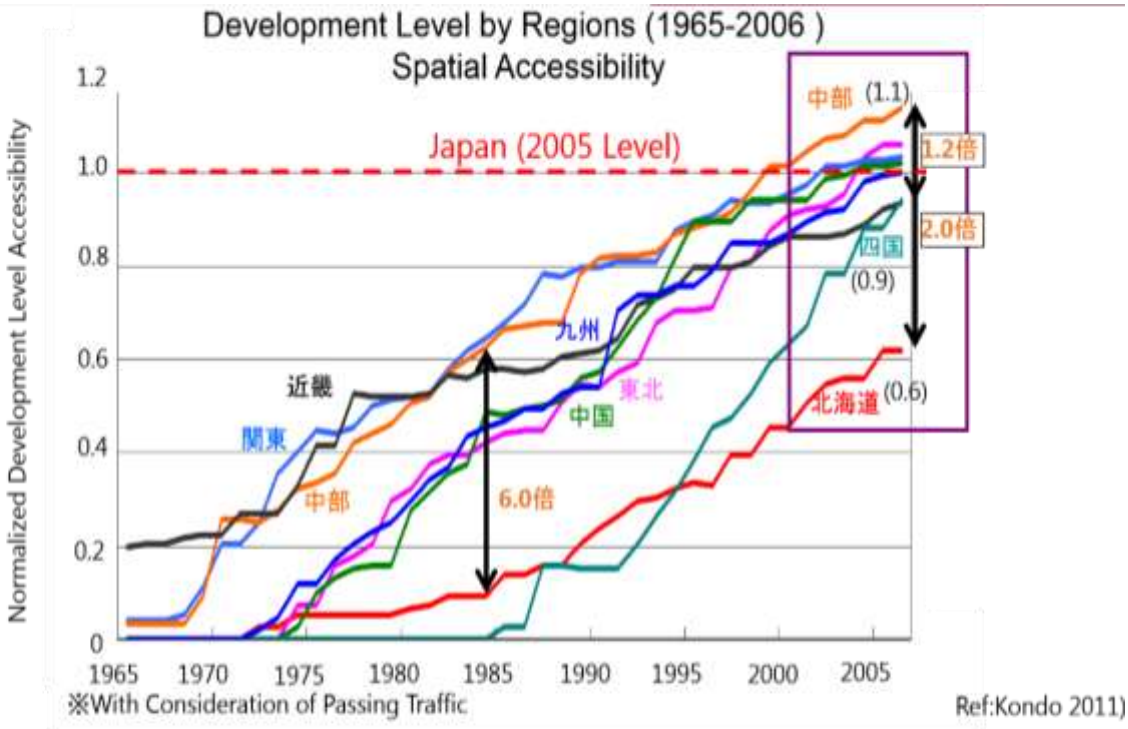


Figure 45 Japan Expressway Development Level (Source: Kondo 2011)

The Expressway development level comparison is conducted by Kondo (2011). The results reveal that the disparity of each region is large at the early stages. In later stages of the development, the disparity between regions become smaller and smaller. The pattern is most advanced region led the high development level in expressway development. Hokkaido and Shigoku have lower development level. I will focus on the role of the expressway in the integrated NDL discussion.

6.1.4 Integrated Development Level Comparison and policy analysis

I integrated the NDL for expressway, HSR and Airport, using the triangle to represent the mode pattern and the integrated development level suggested by the size of the triangle. Each mode at the certain year is compared with the base line year of national NDL. I tracked the changes from 1966 to 2005. The mode pattern of Japanese regions are shown below in figure 24.

The region located in the edge of the country has higher airport development level than other modes. It may reveal the investment decision (or the outcome of the investment) of inter-regional transport infrastructure are more pro air transport. Secondly compared to HSR NDL within these regions, expressway NDL has higher value. The regions located in the middle of the country has higher HSR development level than other modes.

The regions in the middle as well as the advanced regions are taking a more balanced approach in each mode of development in terms of the NDL value are similar in each mode. The size of the triangle reveals the integrated NDL, the advanced regions in Japan does not enjoy the highest NDL.

It helps the policy-maker to make decision on specific mode with the consideration of other modes and made a coordinated decision. Considering the time lag of the impact of construction of infrastructure, it means that the planning and investment decision needs to be coordinated in the long term plan, otherwise will results in a waste in the large infrastructure asset. As the capacity of the infrastructure is not easy to adopt to changes, for example, after building new HSR the existing airport might be affected to lose market. The not only the policy side needs to adopt the changes, if the long term planning can be done in an coordinated way then will avoid the over investment.

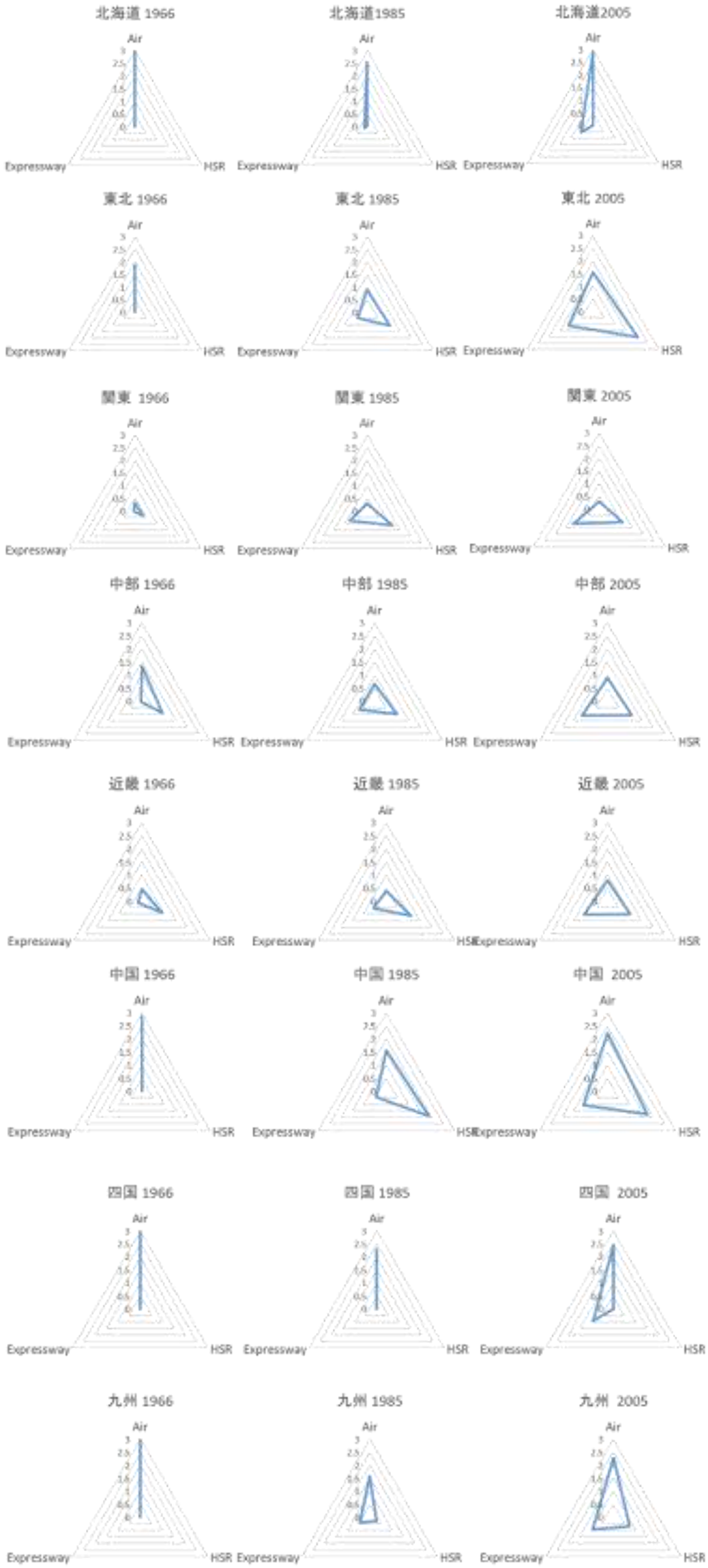


Figure 46 Modes Pattern in Japan (Source: Author)

The detailed discussion of airport and the pattern of several country will be introduced below.

6.3 UK Airports

Regarding airport infrastructure and civil aviation industry, UK is an interesting country to look at for following reasons. 1) UK has long history of civil aviation and once the manufacture of aircrafts. 2) UK's aviation industry carried out privatization of airport since 1980s(Humphreys and Francis 2002). 3) London region are the economic center of UK, Europe and the World. From the number of airport perspective, it has 5 airports and the government is continuing to enhance the airport's capacity within and around London region. 4) Similar with Japan, UK is comparably isolated in term of geographic figure. It would be interesting to compare UK with Japan and draw some insights.

Hereby, I apply the NDL method to exam the development level of airport in UK from 1970 to 2010.

6.3.1 Data Description

The data of airport and the changes are collected from Civil Aviation Authority of United Kingdom. The number of airport is based on the CAA Annual Statistics from 1970s(Aviation and London 1980), using the data in the record of Size of UK Airports from reporting airport. My lab member Nakada San and I jointly compiled the data into regions. The population and geographic data are from UK office for National Statistics (Regional and local statistics 2015). The historical data of regional GDP data is based on the estimation done by Crafts (2005) and EU statistics. Scotland has around 17 airports, 10 out of 17 are located in islands. In the calculation, the airports located in the small island is excluded.

6.3.2 Regions in UK

Figure 47 Regions in UK (From website)

According to UK's statistic year book, UK is divided into 12 regions, shown on the above map. The calculation of the NDL will also be also based on this divisions. The historical GNP per region is not available from the statistic sites(Crafts 2005), the value used in this research is based on the best estimation done by Crafts. The airport number data is obtained from the civil aviation year books from 1960s.

6.3.3 Development Level of Airport –Accessibility from 1970-2010

The base line 1 is the UK national average NDL of the year of 2010

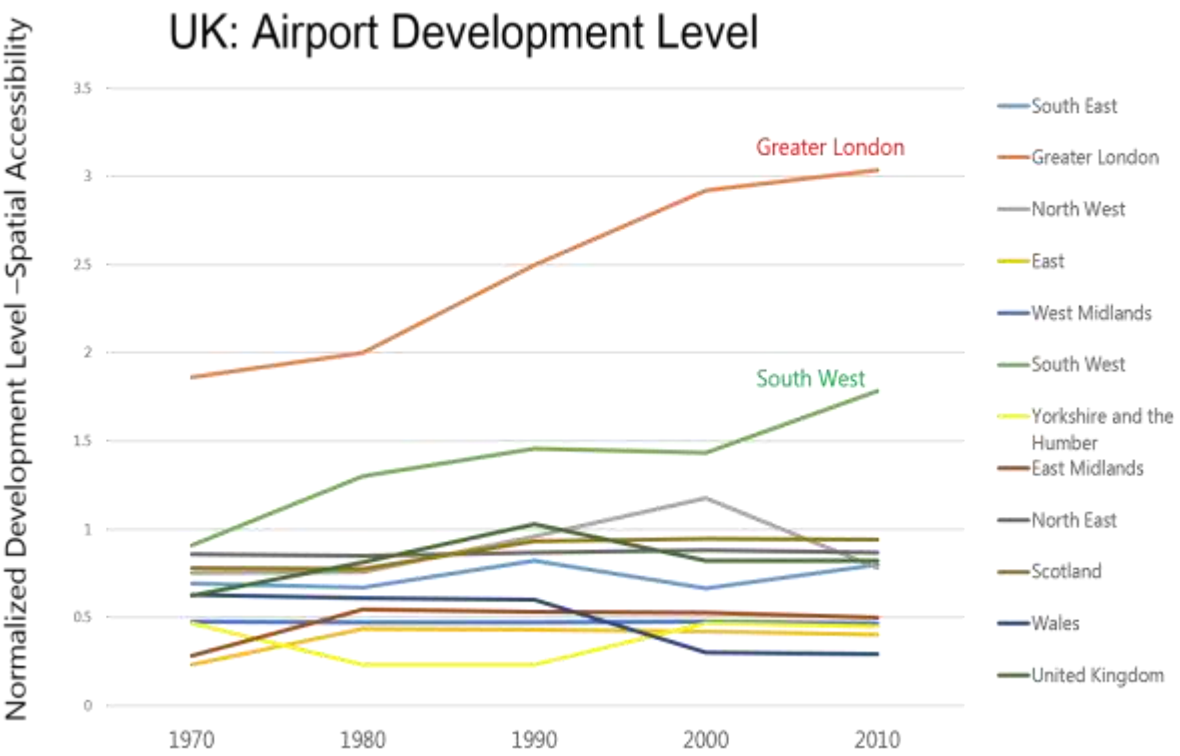


Figure 48 UK Airport Development Level from 1970-2010(Source: Author)

The pattern is quite interesting and very different from Japan. The most advanced regions Great London has the highest development level. Second ranking is combined Great London and South East and then South West region, it is in the same order of economic advancement.

6.3.4 Discussions

It is quite interesting pattern of UK development approach in regions. Firstly the advanced region located the highest level. Secondly they also have the highest increase rate across time. In the contrast, Kanto and Kansai region of Japan are the lowest, the increase rate also low compare to other regions.

I would like to discuss the reasons behind this results from historical reasons, policy reasons and airport strategy setting.

Historically, similar with Japan, a lot of civil airports with the number of 44 are converted from military airports in 1947 (Humphreys 1999). The number of military airports around London are larger than Tokyo regions (Kani T., Hei C., Hitoshi,Ieda 2015). The high level of London regions may results from this historical reason.

After the airports returned to Ministry of Civil Aviation, these airports suffered substantial losses. Then the government facilitated the process of transferring the ownership to local government from 1967 and then further privatize these airports(Humphreys 1999). Then the rationale of maintaining and expanding the operation of airport is more based on market economy. The following maps shown the ownership changes in the year of 1967 and 1997.

Moreover, the strategy setting of Great London airports is for international gateway. The economic interactions between UK and Europe are very active. The mobility is heavily relay on aviation due to the geographic constrains. Hence it may be rationale to

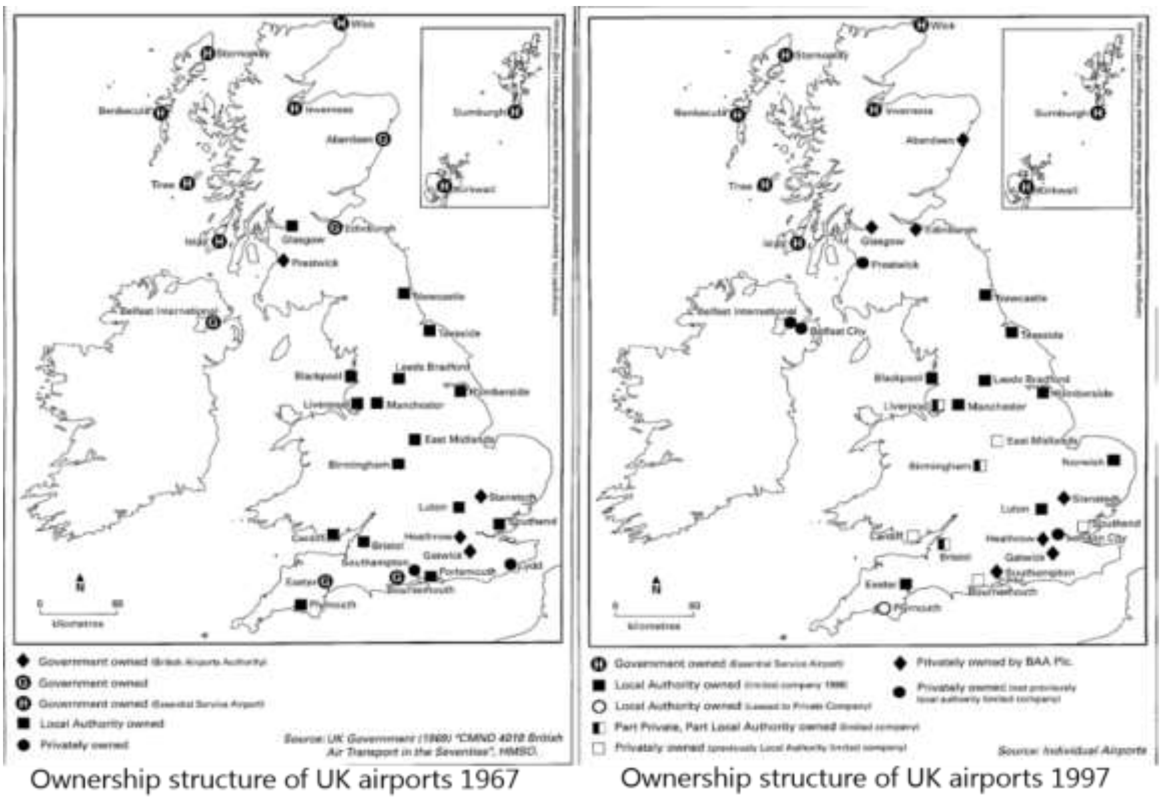


Figure 49 Ownership structure of UK airports (Source: Humphreys, 1999)

focus on enhance the accessibility of air service in London region at the very beginning.

Although, here development level evolution is focused on the accessibility. We could draw some insights from UK government’s policy focus on utilization the existing capacity of airport and continuing enhancing the capacity of Great London airports(UK Airport Commission, 2014). As the time series data of capacity changes are still under the process of compiling by the author, more interesting comparisons are expected after conduct the NDL from both accessibility and capacity perspectives.

Another insights is that London region airport plays the role of international hub airport. Therefore the infrastructure supply also intend to meet that goal compared to other regions in the UK.

6.4 France Airports

France is known as the one of the two biggest aircraft making country. Paris also is served by multi-airports. In term of economic concentration, Paris is also the solo center within France. More importantly, France has a similar HSR structure with Japan. The Paris region is also served well by the HSR network. Hence it will be interesting to exam the development level of each region in France.

6.4.1 Data descriptions

The data of airport and the changes are collected from Statistic year book of Ministry of Transport of France(Bulletin Statistique Traffic Commercial Annee, 1997 to 2011). My lab member Nakada San and I jointly compiled the data into regions. The regional GDP and population data are collected from EU statistics.

6.4.2 Regions in France

Figure 50 Regions in France (Source: Wikipedia)

France will adopt the new regions in 2016. The several existing 16 small regions will be merged into 7 larger regions, and 6 will remain unchanged. The new regions is shown in the Section 6.4.3. The reason of using the new regions instead of old regions is because the old regions are comparably too small for a meaningful comparisons across different countries.

6.4.3 Development Level of airports in France

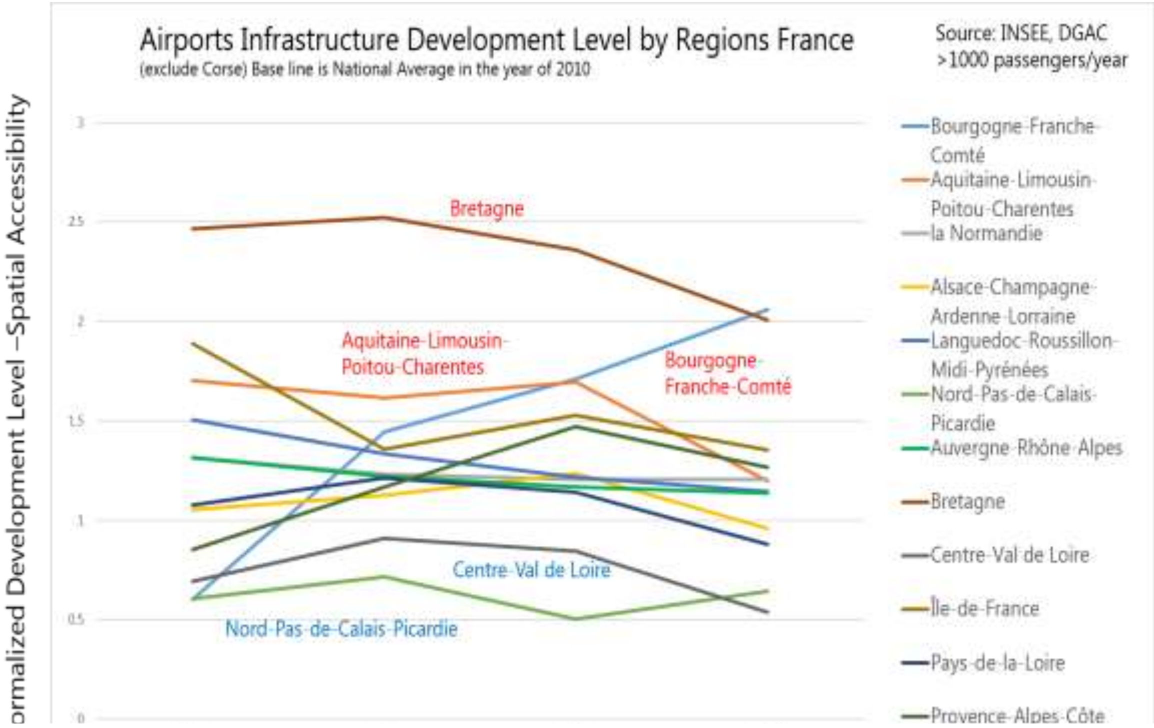


Figure 51 Airport Infrastructure Development Level by Regions in France from 1985-2013 (Source: Author)

The results reveal an interesting pattern that the regions around Paris is continues increasing the development level and located quite high. Then the regions located in the boundary of the countries also enjoyed higher level of development (Bretagne or Brittany, Aquitanie-Limousin-Poitou-Charentes). The hinterlands of the country has lower level of development compared to other regions.

It is in a certain perspective similar to Japan that the regions near the country boundary has higher development level. However, when considering the pattern of the advanced region, Paris region has comparably higher level among all regions after 2000s. It is different from Japan's Pattern. Until now, we have conducted the detailed regional comparison for three large economy in the World, namely Japan, UK and France. All of the three country, shown economic and political concentration into their capital city. However, the airport development pattern of the capital city region are quite different.

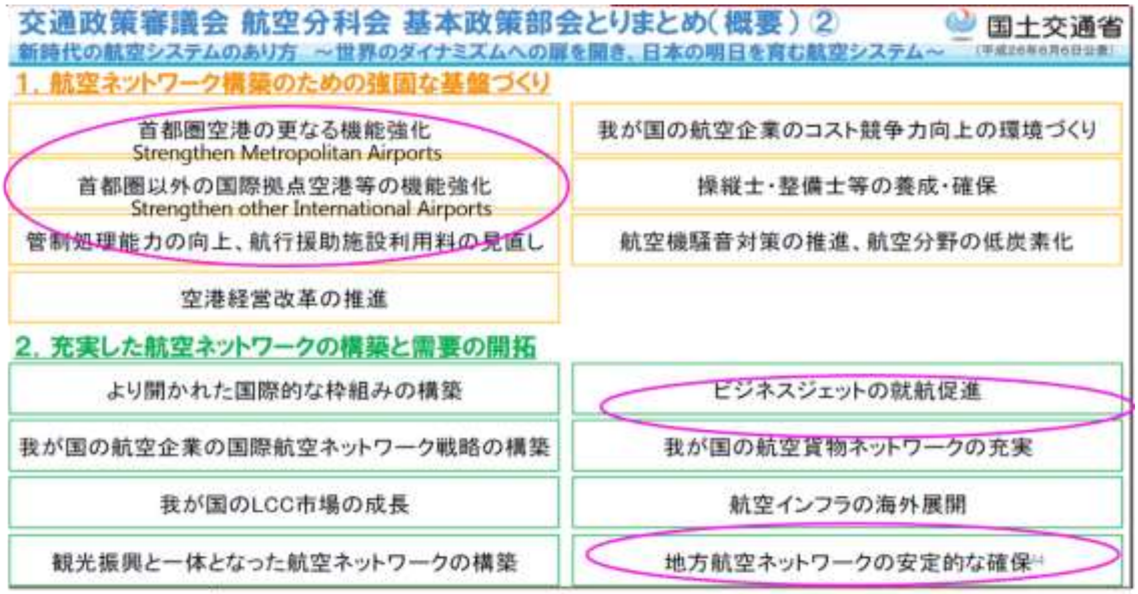


Figure 52 Policy Meetings Conclusions of MILT 2014 (Source: MILT)

As introduced before, the Japanese policy has intend to strengthen the metropolitan airport development since 1990s. However, the policy seems not be effective. Figure 41 shows the policy meetings conclusions of MILT, even in 2014 they still needs to highlights the needs to strengthen the metropolitan airports. They also suggest to strengthen other international airports in Japan as well as emphasizing on the regional network stability.

6.5 Airports Development level in China

China has developed around 100 new airports in the past 30 years in the rapid growing economy period. As the country size is large, air transport also has unique role in connecting the country. Hence, I will like to further compare China with other country's pattern.

6.5.1 The Airport Development Level in China from 1980-2010

The data is based on China Civil Aviation Year Books (China Civil Aviation Statitic Year Book 1990-2010) and compiled by the author into regions. The regions are divided in the common practices of 6 large regions. The base line 1 is the national average of China in the year of 2010.

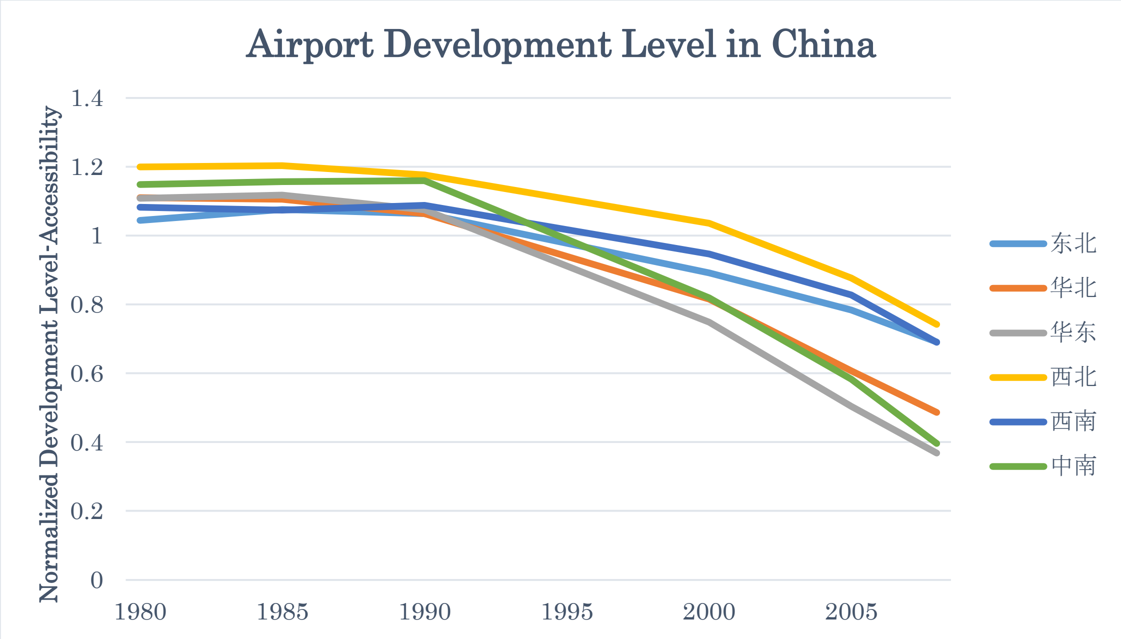


Figure 53 Airport Development Level in China from 1980-2010 (Source: Author)

It is very interesting to see that China's development level is decreasing sharply given the fact that China constructed around 100 new airports. It is probably due to the fast economic growth and population growth and comparable cheap construction cost at these period. At the beginning of the 1980, the level is above 1, this is also benefit partially from the existence of military airports. The gaps between regions also enlarged in recent years.

Then look at the details of each region. The most advanced regions are located in the lowest level after 1990s, namely Huadong region along the east coast (Shanghai located in Huadong region). Followed by other two advanced region Huadong (Beijing and Tianjin located) and Zhongnan (Guangdong province located). Other regions located at the boundary of the country enjoyed comparably higher level. Despite the decreasing trend, the ranking of the regions share some similar pattern with Japan.

Several papers exams the structural and location changes of air transport system including the infrastructure and flight provision, they categorized the cities into 1) political centers such as provincial capitals, 2) and nonpolitical centers mainly supported by industries and trades as "economic-trade center" 3) cities mainly supported by tourism,

4) other

(Jin, Wang, and Liu 2004) They discovered the trend of focus on the political centers first and then the nonpolitical centers as well as cities supported by tourism. However, in my assessment, this trend is not obverse. It might due to the analysis here is at the scale of larger regions.

If we take current capacity constrains for discussion, the capacity constraints and large amount of delay occurs mostly at the lowest NDL level regions, namely Huadong, Huabei and Zhongnan. The users also complained with the access to the airport is not desirable in terms of distance and delay on the expressway due to congestions, especially for the frequent flyers. For Beijing region, the Beijing International Capital Airport opened in 2008 reached the design capacity earlier than expected. The planning for the second Beijing airport had been treated as radical plan at the initial stage. But now, as the congestions at the Beijing International Capital Airport become too serious, people are calling for the completion of the second airports. My research results shed lights on this policy implication that the development level is decreasing compared to other countries as well as domestic regions.

Chapter 7 Application and Policy Analysis of the NDL to Global Region Development Comparison

In this chapter, I am excited to apply the NDL to larger global regions across boundaries of countries. The needs for regional transport infrastructure are rising in this era of globalization and regional cooperation. Just take Asia for example, the ADB report *Infrastructure for a Seamless Asia*(ADB.ADBI 2009) concludes that Asia's trade competitiveness and increasingly inter-depended production network depends on infrastructure connections. Furthermore, it explores and concludes why the regional infrastructure is important to Asia: 1) improve connectivity; 2) reduce the cost of regional and global trade; 3)help to promote regional and global integration; 4) help reduce poverty; v)inclusive development across the region; 5) more efficient allocation of regional resources;6)facilitate the creation of single Asian market.

Hence the needs for assessment method at this scale also emerging. There are several notable attempts to estimate the infrastructure needed for global regions. However, all of them indicated that the data availability is one obstacle to conduct researches for such purposes. The NDL has the advantage to conduct development comparisons when sophisticated and detailed data are not available.

I select European Union as the first global region to conduct NDL analysis. As EU is the most advanced and established regional institution in the world, their development experiences could provide insights for other regions as well as other countries.

In Section 7.1, I briefly discussed the emerging needs for regional transport infrastructure in Asia and EU's experience. Section 7.2 concludes the benefits of applying NDL at this scale of comparison. Section 7.3 presents the results of EU expressway development level in comparison to other countries. Section 7.4 suggests the future applications at the scale of global region.

7.1 Emerging needs for regional transport infrastructure

Within Asia, there are emerging calls for regional cooperation and integration to enhance the trade competitiveness and economic growth, which needs to be supported by regional transport infrastructure (ADB,2009; Madhur, Wignaraja, & Darjes, 2009). Studies suggest that invest in regional infrastructure together with supportive trade agreement will lead to lower trade costs and facilitate mobility improvement and regional integration (Francois, & Wignaraja, 2008; Madhur et al., 2009). ADB report (2009) concludes that the inadequacies of Asia's infrastructure networks are a bottleneck to growth. Bhattacharyay (2009) suggests that in comparison to North American and EU, the level of intraregional trade is relatively low in Asia due to high transport cost.

Learning from EU, the world's most developed regional institution, the institutional setups have been driving the regional infrastructure development in terms of setting policy, setting regulatory framework as well as financing etc (ADB.ADBI 2009). The EU has initiated TEN-T policy to connect the continent since 20 years ago The TEN-T policy also focused on closing the gaps between countries transport network together with Structural and Cohesion Funds dedicated for this purpose. (European Commission Transport Themes Infrastructure-TEN-T-Connecting Europe 2014).

7.2 The benefit of applying NDL to regional transport network.

As stated above, there are emerging needs of building up pan-regions (or regional) transport infrastructure across the globe. The regions in the world are competing, cooperating and learning from each other. Pan-region or regional transport network is a comparably new research area and policy focus. Assessment method is needed to measure the development progress, set the benchmark, assist in investment needs estimation and compare each other, in the scale of world's regions.

The ADB reports reals that there are very limited studies addressing investment needs in transport in Asia (Madhur, Wignaraja, and Darjes 2009). In addition, the availability and quality of data becomes one main obstacle. As these kind of assessment involves many countries, data are less accessible and imbalanced in quality, especially in the regions where dominated by developing countries(ADB.ADBI 2009). The method developed in this research has advantage to conduct assessment in this scope. NDL has advantages to perform larger region comparisons. As in larger regions 'comparison data are less accessible and imbalanced in quality, hence model which required detailed data might not functioning well.

7.3 Apply to EU expressway network

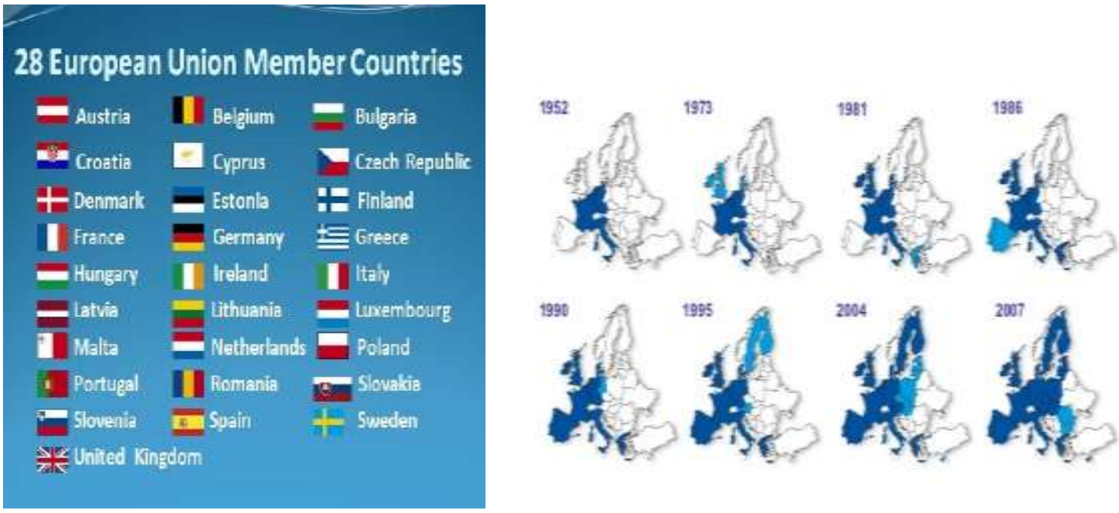


Figure 54 EU member countries and enlargement since 1952 (Source: EU official website)

I collected the data of EU 12 countries as well as EU 28 countries on the expressway development since 1970s from the EU statistic. The construction cost estimation part, the earthquake impact are calculated in a weight average of area. The result are shown as following.

Japan’s development level is below EU 12, however higher than EU 28. The EU 12’s development level is lower than US until around 2000. After Spain join the EU in 1986, Spain has gain a lot of supports from EU in terms of policy, regulation and most importantly funding. From 1996, EU has started to implement the Tran-Europe Network development aiming at enhancing the connectivity between west and east. It also reflected in the figure that EU consistently increases its level.

Most of the priority project of TEN-T are railway and HSR projects aiming at enhancing the connectivity between west and east. (Infrastrcuture-TEN-T-Connecting Europe Priority projects 2014) There are several large scale ongoing HSR projects aiming at connecting the “old and new member countries”. The future completion of these projects will have impact on the development level of inter-regional transport across Europe. (Infrastructure - TEN-T - Connecting Europe-Linking East and West 2014)

Hence, the next step of this research will exam other modes in global region.

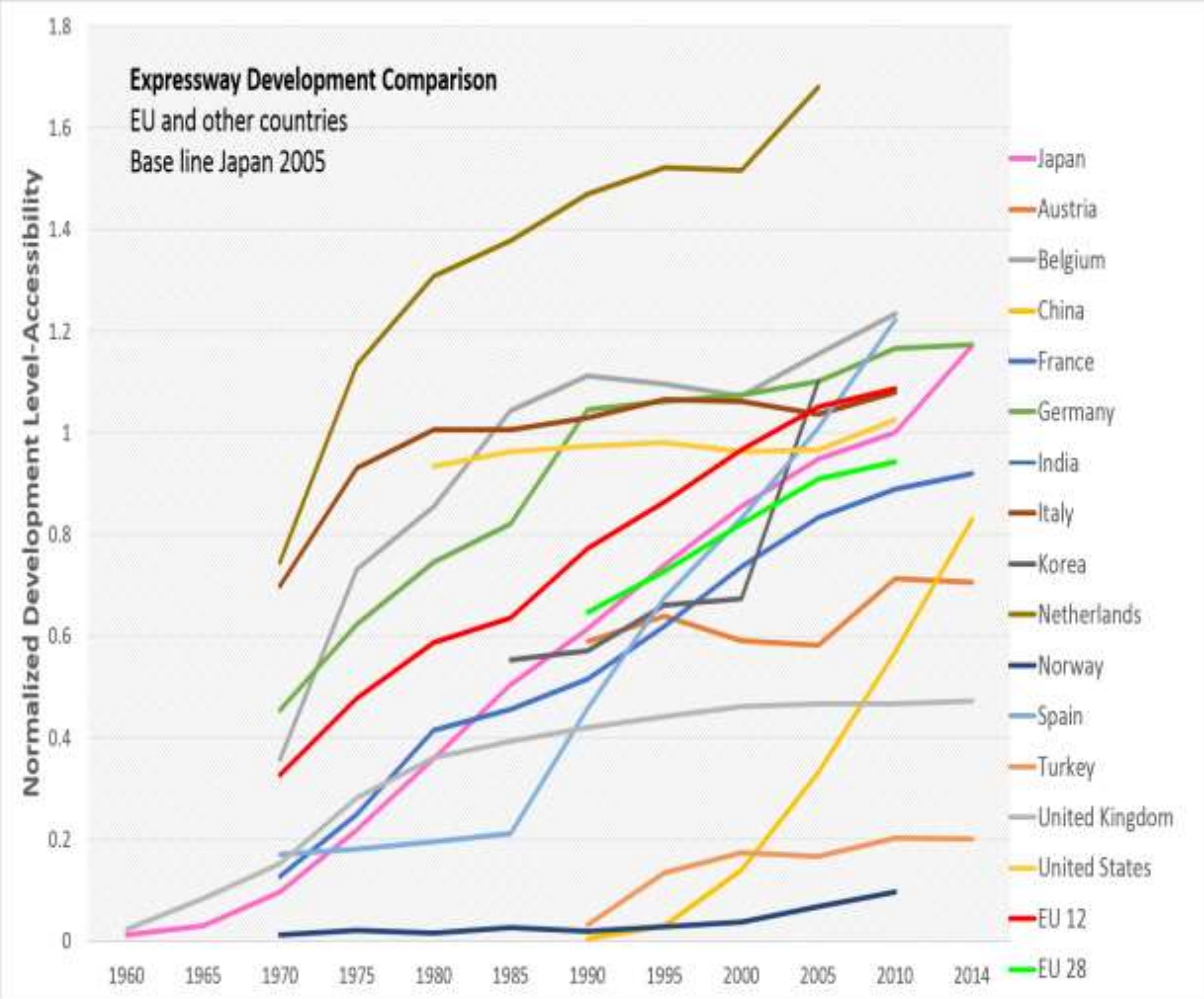


Figure 55 Expressway Development Level Comparison-EU and other countries (Source: Author)

Chapter 8 Conclusions

Inter-regional transport infrastructure is vital for national and regional development. Huge investments are needed in the coming decade in order to cope with the growing demand and deal with issues of maintaining the current existing stock around the world. Assessing current development status, reviewing development history and evaluating the effectiveness of the policy and investment on inter-regional transportation infrastructure will ultimately help the discussion of long-term development strategy.

The objectives of this research are: 1) Develop the practical methodology to assess and compare the development level of inter-regional transport infrastructure (expressway, high-speed railway, airport and all modes). The comparison method should capture the geographic, demographic and economic differences. 2) More importantly, apply the methodology to conduct development level comparisons, policy analysis and draw policy implications.

In this thesis, firstly I further developed the practical methodology of Normalized Development Level (NDL) to assess the development level of inter-regional transport infrastructure including expressway, high-speed rail and airport; Secondly, I apply the method to conduct development level comparisons and policy analysis on 20 countries across the globe from 1960s to 2014. Implications have been drawn for policy-makers in central, local governments as well as international organizations. This chapter summarized the main findings. Then I discuss the limitations of the study and identify opportunity for future works.

8.1 Academic and practical contributions on methodology improvements

In this thesis, I further developed the practical methodology of Normalized Development Level (NDL) to assess the development level of inter-regional transport infrastructure including expressway, high-speed rail, rail and airport. It is not only able to measure the development level of interregional transport infrastructure but also comparable among different countries (domestic regions and global regions) capturing the historical change of each system, and most importantly the patterns towards different mode.

The main contributions in the methodology part are following:

Overall, two indices, namely Normalized Development Level Index on Spatial Accessibility, Normalized Development Level Index on Resources Quantity, are further developed to assess the development level of inter-regional transport infrastructure on spatial accessibility and capacity (resources quantity). An integrated assessment approach on multi-modes infrastructure is achieved, which fills the blank research area. The improvements have been made in the NDL indices are described as follows:

1) Further enrich development level comparison concept through articulating the definitions, essentially the method of which compares the supply and necessity of inter-regional transport infrastructure with other country;
2) Improve the theoretical formation of necessity and justify the assumptions and simplifications of model components, which enables the comparisons based on theoretical sound and cost-effective method;
3) Unify the model construction of each transport modes, which enables the integrated assessment on all modes later on;
4) Add the high-speed rail Normalized Development Level Index on Spatial Accessibility;
5) Enable larger scale application of the method by solving the passing demand issues caused by international traffic which applies gravity model and use trans-country OD data set to estimate the international passing demand;
6) Most importantly, with the above improvements, the method is able to make integrated assessment on all modes. It fills the blank research area of integrated assessment on all modes. Development patterns on different kinds of modes can be identified.

8.2 Main findings in comparison results and policy analysis

This thesis further apply the NDL to assess the development level of inter-regional transport infrastructure followed with policy analysis and implications.

8.2.1 Comparison results of the development level

Comparison results of the development level of expressway, high-speed railway, airport on around 20 countries during 1960s to 2014, are presented in this thesis. It displays the development level changes and enables policy-makers to track the development level of each modes and all modes in the history as well as assess current development status. In detail, the application of the method widely expands to more countries and scales for

1) Country level comparisons: conducted development level comparisons of 15 countries for expressway, high-speed railway, airport and integrated all modes;
2) Domestic region level comparisons: conducts detailed comparisons on 2 countries at regional level, namely Japan and China, for expressway, high-speed railway, airport and integrated all modes;
3) International region level comparisons: conducted assessment on the EU for expressway development;
4) Airport Infrastructure: conducts detailed international comparison on airport infrastructure. The regional development pattern reveals the effectiveness of this method.

8.2.2 Main findings in the comparison results

1) Country level comparisons:

Expressway:

1) General trends: the Netherlands has the highest development level in this international comparisons. The EU countries generally slowed down its development pace after 1975s. The development level of Spain has a sharp increase after joining the EU in 1986. China and Korea are observed to have the highest development pace among the selected countries.
2) Regarding the Netherlands, the rationale of the comparatively high level of development, is partially because of its transport and logistic sector has been playing key role in its economy as the direct contributor, while transport infrastructure built by most of other countries are mainly for the indirect contribution to economy growth. Similar approach can be observed in Singapore’s port and airport development.
3) In the EU, the trend of slowing down the development after 1975s can be interpreted as the reflections on the oil dependency. As the oil crisis occurred in the mid-1970s, the Netherlands revised its expressway development master plans into various

versions with lower density comparing with the version before the oil crisis. Other EU countries also share similar development pace, which is slowed down after 1975s. Another reason is many countries in the EU started to shift the focus of regional development to metropolitan development after 1980s.

4) Spain enjoyed a sharp increase in the development level after joining the EU in 1986. It catches up with the EU 12 countries' benchmark level in 2005. It has benefited from the EU funding and policy on improving the connectivity in the EU.
5) The highest (or exceptional) growth rate have been observed in China and Korea. It is partially due to the acceleration of investment on infrastructure in response to the Asia financial crisis in 1997 and globe financial crisis in 2008.

High-Speed Rail:

General trends: Japan maintained the highest development level until 2010. Korea surpassed Japan in 2010 and several countries are approaching the same development level as Japan. After 2000, the countries newly adopted the high-speed railway technology increased their development level sharply, which shapes a new dynamic in the high-speed railway development in terms of technology development as well as expansion of projects.

Airports:

China's airport development level decreased sharply comparing with other countries. Take its aggressive development in expressway and high-speed railway into consideration, China has been taking a different approach in airport development.

Integrated Assessment on all modes

1) In general, this research integrates the NDL for expressway, high-speed railway and airport, using the triangle to represent the mode pattern and the integrated development level suggested by the size of the triangle. Each mode at the certain year is compared with the base line year of national NDL 1 of Japan. The shape of the triangle indicates national "mode choice" or development outcomes.
2) Several countries are more expressway oriented development, namely Italy, Belgium and the Netherlands. Another group is the countries which have relatively higher level in airport than other modes, including the UK, France, Germany, Norway and the US. Norway is more relied on the airport infrastructure in the inter-reginal

development. One more interesting pattern is that Korea and China both developed towards expressway and high-speed railway. It might indicate these countries have made wise decision toward the energy efficient mode. In terms of the overall integrated development level, Japan, Germany, Korea, the US and Belgium have the highest level. Lower density countries have the pattern more towards airport development with only one exception, China.

2) Domestic region level comparisons:

Japan Airport:

1) The airport development in Japanese regions has following patterns: a) initial development level is high; b) the disparity between regions becomes gradually larger; c) the level of advanced regions are the lowest; d) regions located in the edge of the country have higher development level.
2) A gap between infrastructure provision and operation has been identified in Japan's civil aviation development.
3) The policy, which intended to focus the development in metropolitan airports, is not effective in the past twenty years.

Japan Expressway:

The disparity between regions becomes smaller and smaller. It demonstrates the effectiveness of Japanese policy on regional balance development

Japan High-speed Railway:

The development of high-speed railway started from the advanced regions, namely Kanto and Kansai as well as Kinki. Later other regions caught up with the advanced region. The Chugoku region have a high development level, partly because of its location, which plays the role of connecting west and east. Similar trend has been observed in China as well.

Japan Integrated All Modes:

The regions located in the edge of the country have higher airport development level than other modes. It might reveal the investment decision (or the outcome of the investment) of inter-regional transport infrastructure are more toward air transport. Secondly, compared to high-speed railway, NDL within these regions, expressway NDL has higher value. The regions located in the middle of the country have higher high-speed railway development level than other modes. The regions in the middle as well as the advanced regions are taking a more balanced approach in each mode of development as the NDL value are similar in each mode. The size of the triangle reveals the integrated NDL. The advanced regions in Japan do not have the highest NDL. It helps the policy-maker to make decision on specific mode with the consideration of other modes, in a coordinated manner.

3) International region level comparisons: Expressway Development of the EU

The results reveal the expressway development trend of the EU 12 and the EU28, which can assist the EU and other region to set the benchmark for its expressway development.

4) International Comparison on Airport Infrastructure Development

The metropolitan regions in Japan locate in the lowest bound of the development level across the entire country. In order to draw insights from international comparison, we have conducted the detailed regional comparison for another three large economy in the World, namely the UK, France and Germany. The findings are the metropolitan regions in all the other three countries have comparably high development level. It further reveals the issue that Japan should focus on the improvements of its airport development in its metropolitan regions.

In the first stage of this research I further develop the practical methodology of Normalized Development Level (NDL) to assess the development level of inter-regional transport infrastructure including expressway, high-speed railway and airport. It is not only able to measure the development level of inter-regional transport infrastructure but also comparable of capturing the historical change of each system among different countries (domestic regions and international regions), and most importantly the patterns towards different modes. It is the first time that the development level comparison is measured with consideration of economic, demographic and geographic difference as well as the attributes of different transport modes. In the second stage, I apply the method to conduct development level comparisons and policy analysis on 20 countries across the globe from 1960s to 2014. Implications have been drawn for policy-makers in central, local governments as well as international organizations.

8.3 Limitation and Future work

Some of the limitation and future work will be addressed in the future works. Methodology side: 1) the integration on the capacity perspective has not been fully fulfilled. 2) The expansion to conventional rail has not addressed the issues of how to deal with large disparity in the railway quality in terms of speed and track attributes. 3) There can be second option of integrating the development level for all modes by creating additional single index. It might be the future work as well. 4) On the cost estimation part, empirical data of operation and maintenance cost will enhance the estimation. 5) Further conduct sensitive test on the assumptions and key factors will shade more lights on the results interpretation. 6) The different needs from freight and passengers are handled implicitly. Further research could improve this part as well. 7) There still rooms to add discussions on the improvements on the variable and parameters: the capacity and delay relationship, travel speed on the normal network, discussion on the station location's impact. 8) In the airport mode, adding the consideration of international flights explicitly will enhance the assessment.

On the application and policy analysis side, several country and regions data can be further collected. It will enable me to draw more development pattern from adding interesting cases. As the development level defined in this research is focus on the infrastructure, the operation and performance facts can be further added and analysis in order to draw more policy implications. As identified from this research, the discussion of the gap between infrastructure provision and operation can be very revealing.

Promotion and the NDL index. The ideal goal is the NDL index will be adopted in the development level assessment worldwide like GDP, GINI and other popular method and index. In order to do so, there are several parts needs further improvement. One is through wider application and publication. Second is improve the virtualization of the NDL to more user friendly format.

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Annex 1

Table 1 Summary output of multi regression (4.2)

SUMMARY OUTPUT of Multi Regression

Regression Statistics	
Multiple R	0.718631302
R Square	0.516430948
Adjusted R	0.515498137
Standard Error	1.729372202
Observations	2598

	df	SS	MS	F	Significance F
Regression	5	8278.768	1655.	553.6289	0
Residual	2592	7751.968	2.990		
Total	2597	16030.74			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-13.2184632	0.87815	- 15.05	3.73E-49	- 14.9404	- 11.4965	- 14.9404	- 11.4965
Distance	-0.00081537	2.39E-05	-	6.7E-211	-	-	-	-
ln GDP O	0.428313451	0.037602	11.39	2.29E-29	0.35458	0.50204	0.35458	0.50204
ln GDP D	0.710176474	0.146519	4.847	1.33E-06	0.42287	0.99748	0.42287	0.99748
ln population	0.237987648	0.037648	6.321	3.04E-10	0.16416	0.31181	0.16416	0.31181
ln Population	0.266213971	0.148012	1.798	0.072199	-	0.55644	-	0.55644

Table 2 Summary output of Regression results (4.4)

SUMMARY OUTPUT of Multi-Regression

Regression Statistics	
Multiple R	0.754372
R Square	0.569077
Adjusted R Square	0.568246
Standard Error	1.632523
Observations	2598

ANOVA

	df	SS	MS	F	Significance F
Regression	5	9122.719	1824.544	684.5985	0
Residual	2592	6908.016	2.66513		
Total	2597	16030.74			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-6.15551	0.875595	-7.03009	2.63E-12	-7.87245	-4.43858	-7.87245	-4.43858
ln distance	-1.56971	0.038979	-40.2708	8E-276	-1.64615	-1.49328	-1.64615	-1.49328
ln GDP O	0.410547	0.035504	11.56351	3.43E-30	0.340928	0.480165	0.340928	0.480165
ln GDP D	0.309126	0.13809	2.238581	0.025268	0.038348	0.579905	0.038348	0.579905
ln population O	0.311998	0.035586	8.767515	3.24E-18	0.242219	0.381778	0.242219	0.381778
ln Population D	0.699312	0.13918	5.024317	5.4E-07	0.426386	0.97223	0.42638	0.97223

Annex 1

Table 3 Summary output of Regression results (4.6)

SUMMARY OUTPUT 1

Regression Statistics	
Multiple R	0.612607
R Square	0.375287
Adjusted R Square	0.362486
Standard Error	1.967672
Observations	250

	df	SS	MS	F	Significance
Regression	5	567.5167	113.5033	29.31589	2.86E-23
Residual	244	944.7032	3.871735		
Total	249	1512.22			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper	Lower	Upper
Intercept	-0.50587	2.70659	-0.1869	0.851893	-5.83713	4.825396	-5.83713	4.825396
distance	-0.0017	0.000213	-7.95164	6.85E-14	-0.00212	-0.00128	-0.00212	-0.00128
ln GDP 0(million	0.972717	0.157578	6.172926	2.78E-09	0.662331	1.283104	0.662331	1.283104
lnGDP d *million	0.384276	0.147991	2.596621	0.009986	0.092774	0.675779	0.092774	0.675779
ln Population O	-0.36084	0.184515	-1.95559	0.051655	-0.72428	0.002609	-0.72428	0.002609
lnPopulation D	0.065427	0.187505	0.348934	0.72744	-0.30391	0.434762	-0.30391	0.434762

Table 4 Summary output of Regression results (4.7)

SUMMARY OUTPUT 2

$f(r_{ij}) = r^{\varepsilon}$

Regression Statistics	
Multiple R	0.647321
R Square	0.419025
Adjusted R Square	0.407119
Standard Error	1.897542
Observations	250

ANOVA

	df	SS	MS	F	Significance F
Regression	5	633.6575	126.7315	35.19668	4.79E-27
Residual	244	878.5625	3.600666		
Total	249	1512.22			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	6.987381	2.51725	2.7758	0.005933	2.029069	11.94569	2.029069	11.94569
ln GDP 0(million current	1.101456	0.149236	7.380657	2.47E-12	0.807502	1.39541	0.807502	1.39541
Ln GDP d *million	0.387506	0.142483	2.719672	0.007004	0.106853	0.668159	0.106853	0.668159
ln Population O	-0.43548	0.173099	-2.51579	0.01252	-0.77644	-0.09452	-0.77644	-0.09452
Ln Population D	0.168574	0.181227	0.930182	0.353196	-0.1884	0.525544	-0.1884	0.525544
ln distance	-1.68745	0.181585	-9.29288	8.7E-18	-2.04512	-1.32977	-2.04512	-1.32977

ANNEX 2-A: Length of Expressway Network in the World from 1960 to 2014

Expressway Length(km)	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Austria							1445	1596	1633	1677	1719	1719
Belgium			501	1051	1251	1534	1666	1666	1702	1747	1763	
China							522	3422	16314	41005	74100	111900
France			1542	3119	5287	5885	6824	8275	9766	10800	11392	11882
Germany			4461	6207	7538	8350	10854	11190	11712	12363	12819	12917
Italy			3913	5329	5900	5955	6193	6435	6478	6542	6668	
Japan	71	189	649	1519	2579	3721	4661	5677	6617	7383	7803	9143
Korea						1415	1550	1886	1996	3367		
Netherlands			975	1525	1798	1915	2092	2208	2265	2600		
Norway			41		57		73	107	144	264	381	
Spain			1585	1746	1923	2117	4693	6962	9049	11432	14262	
Turkey							281	1246	1674	1667	2080	2127
UK	153	566	1057	1975	2556	2813	3070	3269	3467	3518	3558	3645
USA					77078	81685	84880	88054	89426	92003	99005	

The author compiled the data from World Bank Databank, EU statistic, USA DOT statistic and China statistic year books.

ANNEX 2-B: Length of HSR Network in the World from 1980 to 2010

Country Name	1980	1985	1990	1995	2000	2005	2010
Belgium					72	137	209
China						405	4580
France		419	710	1177	1281	1540	1896
Germany			90	447	636	1196	1285
Italy		224	224	248	248	248	923
Japan	1069	1804	1804	1921	2228	2452	2534
Korea						330	412
Netherlands							120
Russia							650
Spain				471	471	1090	2056
Turkey							235
UK						74	113
US					362	362	362

ANNEX 2-C: China HSR Length by regions from year of 2008

HSR Length(km) by regions	2008	2010	2012	2014
华东（山东 江苏 安徽 浙江江西 福建 上海） **Huadong Region** (Shandong, Jiangsu, Anhui, Zhejiang, Jiangxi, Fujian, Shanghai)	719.688	2025.778	3054.778	4417.778
华北（北京 天津河北 山西内蒙古） **Huabei** (Beijing, Tianjin, Hebei, Shanxi, Neimenggu)	20.25	218.15	975.15	1232.15
华中（湖北 河南 湖南） **Huazhong Region** (Hubei, Henan, Hunan)	157.773	1487.773	2418.773	2979.273
华南（广东 广西 海南） **Huanan Region** (Guangdong, Guangxi, Hainan)	0	473	583	940
西南（ 四川 云南 贵州 西藏 重庆） **Xinan Region**(Sichuan, Yunnan, Guizhou,Tibet, Chongqing)	0	198.7	198.7	547.2
西北（宁夏 新疆 青海 陕西 甘肃） **Xibei Region**(Ningxia, Xinjiang, Qinghai, Shanxi,Gansu)	0	165	165	313
东北（ 辽宁 吉林 黑龙江） **Dongbei Region** (Liaoning, Jining, Heilongjiang)	383.75	383.75	1287.75	1377.75
全国 China	1281.461	4952.151	8683.151	11807.15

The author compiled the data from various statistic website and HSR route introduction site.

ANNEX 2-D: Japan HSR Length by regions from year of 1965

The author compiled the data from various statistic website and HSR route introduction site.

HSR Length(km)	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
北海道	0	0	0	0	0	0	0	0	0	0	0
東北	0	0	0	0	344.1	344.1	431.1	620	716.6	798.6	798.6
関東	76.7	76.7	76.7	76.7	348.2	348.2	348.2	366.7	366.7	366.7	366.7
中部	290.4	290.4	290.4	290.4	440.8	440.8	440.8	539.7	539.7	539.7	767.7
近畿	148.3	148.3	254.2	254.2	254.2	254.2	254.2	254.2	254.2	254.2	254.2
中国	0	0	371.2	371.2	371.2	371.2	371.2	371.2	371.2	371.2	371.2
四国	0	0	0	0	0	0	0	0	0	0	0
九州	0	0	76.6	76.6	76.6	76.6	76.6	76.6	203.6	203.6	334

ANNEX 2-E: The Number of Airports in the World

Country Name	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2014
Austria											6	
Belgium											5	
China					67	78	91	121	130	135	165	202
France									:	66		
Germany									:	74	78	
Italy											43	
Japan	30	45	47	48	49	49	51	56	61	64	65	65
Korea											27	
Netherlands											5	
Norway											65	
Spain											42	
Turkey									14	14	43	48
United Kingdom			43	44	44	56	55	57	59	61	57	56
United States					607	533	541	566	536	514	498	510

The author compiled the data from various statistic website: China Civil Aviation Year Book, EU statistic, Japan Civil Aviation Statistic (excluded the airports on the island), UK Civil Aviation Authority, USA CAA

ANNEX 2-F: The Number of Airports in Japan by regions

Runway Length	**1951**	**1955**	**1960**	**1966**	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**
北海道													
>=3000						1	1	1	2	2	3	3	3
3000->=2500	1	1	1	2	2	1	2	2	2	2	5	5	5
2500->=1500			1	0	0	2	1	4	5	5	4	4	4
1500->=914			5	9	9	7	7	4	3	3	1	1	1
under 914					1	1	1	1	1	1	1	1	0
Airport Number	1	1	7	10	11	11	11	11	12	12	12	12	11
東北(青森、岩手、秋田、宮城、山形、福島)													
>=3000											1	2	2
3000->=2500			1	0	0	0	0	1	1	2	2	3	3
2500->=1500				1	1	0	0	1	2	2	3	1	1
1500->=914		1	1	5	5	6	6	4	3	3	3	3	3
under 914													0
Airport Number	0	1	2	6	6	5	5	5	5	6	8	8	8
関東(群馬、栃木、茨城、埼玉、東京、千葉、神奈川)													
>=3000				2	2	2	3	3	3	3	3	3	3
3000->=2500		1	1	0	0	0	0	0	0	0	1	1	5

2500->=1500	2	1	1	1	1	1	1	1	1	1	0	1	0
1500->=914													
under 914			1	1	1	1	1	1	1	1	1	1	1
Airport Number	1	1	2	2	2	2	3	3	3	3	3	3	4

中部(山梨、長野、新潟、富山、石川、福井、静岡、愛知、岐阜)

>=3000												1	1
3000->=2500			1	2	2	2	2	2	2	2	2	3	4
2500->=1500		2	2	1	1	2	2	3	3	4	4	5	5
1500->=914				4	4	3	3	2	2	1	1	1	1
under 914													
Airport Number	0	2	3	6	6	6	6	6	6	6	6	8	9

近畿(三重、滋賀、京都、大阪、兵庫、奈良、和歌山)

>=3000					1	1	1	1	1	2	2	2	3
3000->=2500												1	1
2500->=1500	1	1	1	1	1	1	1	1	1	1	2	2	2
1500->=914		2	2	2	3	3	3	3	3	4	3	3	3
under 914													
Airport Number	1	2	2	2	3	3	3	3	3	5	5	6	6

中国(鳥取、島根、岡山、広島、山口)

>=3000											1	1	1

3000->=2500										2	1	1	2
2500->=1500		1	1	0	2	3	4	4	4	5	5	5	4
1500->=914			1	5	4	3	2	2	2	1	1	1	1
under 914		1	1	1	0	0	0	0	0	0	0	0	0
Airport Number	0	2	3	6	6	6	6	6	6	8	8	8	8
四国(香川、徳島、高知、愛媛)													
>=3000													
3000->=2500									1	2	2	3	3
2500->=1500				2	2	3	3	4	3	2	2	1	1
1500->=914		2	3	2	2	2	2	1	1	1	1	1	1
under 914													
Airport Number	0	2	3	4	4	5	5	5	5	5	5	5	5
九州(福岡、佐賀、長崎、大分、熊本、宮崎、鹿児島、沖縄)													
>=3000						2	3	3	3	3	3	3	3
3000->=2500					1	3	2	2	3	3	3	3	4
2500->=1500	1	2	3	4	4	3	4	4	3	3	4	4	3
1500->=914		2	5	4	3	1	1	1	1	1	2	2	2
under 914				1	1	2	1	1	2	2	3	3	3
Airport Number	1	4	8	9	9	10	10	10	11	11	14	14	14