Competitive Strategy for the Proposed Texas High Speed Rail Project: A System Dynamics/ CLIOS Process Approach

by
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Abstract

The Texas High-Speed Rail (HSR) is an unprecedented US project proposed by a private company. This project has many uncertainties because it will be funded only by the private sectors and it is the first US HSR project using foreign technology. The HSRs are huge and complex systems involving political, economic and sociotechnical issues that are affected by and affect various stakeholders. Therefore, it is necessary to grasp the "whole picture" of the project to plan effective strategies to make it successful. The objective of this thesis is to identify how we can improve the system performance and propose recommendations to guide the project toward success.

The CLIOS Process is applied to identify the current circumstances surrounding the project. Comparative study of HSR with other transportation modes and market analysis are conducted to identify competitive advantages of the HSR system and how to utilize these advantages to compete with other transportation modes. After these qualitative analyses, pricing strategy, capacity management and accessibility management are identified as the three "key factors for success."

Based on the results, the System Dynamics (SD) approach is applied. Conceptualization of the HSR system by causal loop diagrams (CLDs) clarifies several feedback interactions between key variables, such as ridership, load factor, total travel time and fares. Then, the numerical SD model is created to conduct quantitative analysis over time. Sensitivity analysis for each policy parameter suggests how the HSR operator could improve system performance by implementing different strategies in the short to long run.

Thesis Supervisor: Joseph M. Sussman

Title: JR East Professor Emeritus of Civil and Environmental Engineering and Engineering Systems

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Chapter 1: Introduction

1.1 Motivation

It is surprising that the United States does not have any high-speed rail (HSR) networks for passengers as Japan, many countries in Europe and China do, despite the economic benefits of HSR systems. In 1994, Thomson compared the situation in the US with other countries having HSRs and held that ”The USA certainly does not lack the capability nor the resources to put theory into practice” [1]. Since then more than 20 years have passed, but the US still does not have HSR for passengers as one of the public transportation modes. Todorovich et al. [2] claimed that compared with other modes, HSR has the advantage that it can easily connect cities located 100-600 miles apart. For less than 100 miles travel, highways would be more suitable; for more than 600 miles, flight is preferable to HSR. For the intermediate-range travel, HSR provides fast and frequent service with high capacity. Taking advantage of such characteristics, HSR networks have played an important role in economic development since the 1960s in Japan and the 1970s in Europe. As these countries' history has illustrated, HSR can potentially earn back the huge cost of initial investment by creating large numbers of jobs during its construction and continuing operation, reducing usage of private automobiles and traffic congestion, and suppressing air pollution and emission of greenhouse gas. However, despite these advantages, the development of HSR systems has been neglected like an “orphan child,” American Public Transportation Association (APTA) claimed [3]. In the US, after World War II, private vehicles and commercial air flights gradually dominated the interregional transportation market. Therefore, the US became much more dependent on fossil fuels, and the unwanted consequences could likely be improved by implementing a reliable and environmentally friendly HSR system, which uses electric motor instead of diesel engine.

1.2 Research Objective

What have delayed HSR projects in the US are mainly political conflicts, not technical reasons even in the case that financial viability seems to be secured. Thus, as the Texas Shinkansen project has done, avoiding those political conflicts is the effective way to make things proceed by constructing HSR only within one state and receiving no US government funding (This will be discussed in Chapter 2 in detail). HSR projects are generally considered to be public projects that need large amount of public funding and support, so the Texas HSR project is characterized as the first case of 100% privately funded HSR project in the world. Thus, firstly, we need to analyze how this project will be affected by several actors both in the public and private sectors, domestic and international institutions. Then, we need to consider future HSR ridership, which will be a quite important indicator of making the private project successful. The purpose of this research is to answer the following main questions:

・What types of characteristics can we find out from the Texas HSR project, which is driven by the private sector?
・What are the strengths of a HSR system to serve as a form of intercity transportation, and how could we utilize them to make the modal shift happen in the car- and flight-oriented society like Texas?
・What competitive strategies will affect strongly HSR ridership after its implementation in Texas?

This research will show the possibility of HSR to change the transportation systems in the US and basic understandings of what strategies can make the private project successful and sustainable. The additional purpose is to clarify the role that HSR should take in the future intercity transportation systems in the US, and to make policy recommendations considering a potentially new era of transportation.

1.3 Thesis Outline

This thesis is structured as follows:

Chapter 2 gives an overview of HSR projects in the US. Political arguments for HSR projects and several examples of both public and private projects are shown.

Chapter 3 introduces an overview of the proposed Texas HSR project. This chapter shows the current circumstances surrounding the Texas HSR project, such as stakeholders, technical aspects, and challenges the project has to cope with.

Chapter 4 analyzes the current situation of the Texas HSR project from political, social, economic, environmental and technical viewpoints. This analysis is based on the CLIOS Process [4] by following the procedure of its system representation stage.

Chapter 5 studies general HSR's competitive advantages with other transportation modes at first, then discusses technological advantages of the Japanese Shinkansen system used for the proposed Texas HSR line. This comparative study is conducted as the first "ornament" of the CLIOS Process of design, evaluation and selection of the strategic alternatives.

Chapter 6 analyzes the intercity passenger market using the framework of the Strategic Triangle [5] from the viewpoints of customer, corporation and competitor. In addition, comparisons between the Taiwan and Texas HSR project are conducted to identify their similarities. This market analysis is introduced as the second "ornament" of the CLIOS Process of design, evaluation and selection of the strategic alternatives.

Chapter 7 introduces the System Dynamics approach as the third "ornament" of the CLIOS Process to conduct quantitative analyses.

Chapter 8 describes the simulation results of the System Dynamics modeling in detail. Firstly, the system conceptualization is conducted to identify several important feedback structures. Then, the numerical model is created to conduct quantitative analyses to evaluate strategic alternatives over time.

Chapter 9 summarizes important findings of this research, and makes some recommendations for the Texas HSR operator.

We now proceed our journey with Chapter 2.

Chapter 2: Overview of High Speed Rail Projects in the US

2.1 Background

After the 1950s, there have been several policy proposals of HSR construction as well as the construction of interstate highways. Most recently, in April 2009, as one of the economic stimulus packages right after the financial crisis in 2008, the Obama administration proposed “A Vision for High Speed Rail”. Based on the American Recovery and Reinvestment Act (ARRA), as one of the government’s eye-catching policies, the federal government selected 13 megaregions as possible locations to construct HSR as shown in Fig. 2-1, and it budgeted more than $53 billion during the first 6 years for the initial research and construction cost [6]. This project was supposed to involve huge spending on economic pump-priming measures comparable to the Interstate Highway Act of 1956 proposed in the administration of President Eisenhower. The new project claimed that HSR is a complementary and alternative transportation mode to automobile and air travel in the U.S., and it could establish environmentally friendly transportation networks not heavily dependent on fossil fuels [7]. However, this proposal was faced with fierce opposition from some political groups, which were oriented toward “small government” including the Republican Party holding a majority in the House at that time. Some states, like Wisconsin and Ohio, decided to abandon the plans completely, claiming that they imposed vast financial burden on these states. The plan in Florida, as shown in Fig. 2-2, was considered to be the most likely candidate for the first HSR construction in the U.S., using foreign technology from Japan, Europe, or China [8]. However, this plan connecting Tampa to Orlando by an HSR line was finally rejected by Governor Rick Scott, who was elected in 2010, supported by the ultra conservative Tea Party. He decided to return the federally budgeted $2.3 billion to the federal government and completely withdraw from the plan. The reasons why he opposed to the project were that the construction, maintenance and operating cost would be high in the future and place an enormous financial burden on the state, and some estimation suggested that the passenger demand was overestimated. Therefore, its revenue from the passengers’ fare would not be sufficient, and the project might need a large amount of subsidies from the state government to maintain operation; if the project were cancelled before completion, the financial aid from the federal government would have to be returned. This political opposition stemmed from the fundamental fear that the public deficit would increase enormously by spending too much public funding on the capital cost for HSR projects.

2.2 Pros and Cons for High Speed Rail Projects

Since the announcement of A Vision for High Speed Rail in America [6], various institutions including several think tanks have been engaged in dialogue for or against the plan, and no fixed consensus opinion for the construction of HSR has developed in the US. Some conservative think tanks, such as Heritage Foundation supporting the abandonment of the Florida HSR project [9] and Cato Institute [10], are well known to have a large impact on the American policy; they have declared the opposition to the HSR projects in unison. Reason Foundation, established by a Libertarian group and has an ideology to support the entire liberty of an individual and free market [11], is an example of such think tanks. Their report [12] showed strong opposition by arguing that Japanese and European HSRs, which are seemingly successful fiscally, spent large amounts of public funding for their initial investment of construction, and all were constructed based on the existing demand for rail corridors. Reason Foundation's report opposed the HSR projects in the US claiming that in contrast with the EU and Japan, HSR cannot attract sufficient demand in the modern US, which already has car-centric transportation systems. It also claimed that the expected profitability from HSR projects in the US is much less than it is in other countries, so the private companies cannot enter the market [12]. The common idea of such opposition is extracted from their ideology that supports small government and therefore resists government expenditure and supports auto-centered society as a symbol of a freedom and individuality.

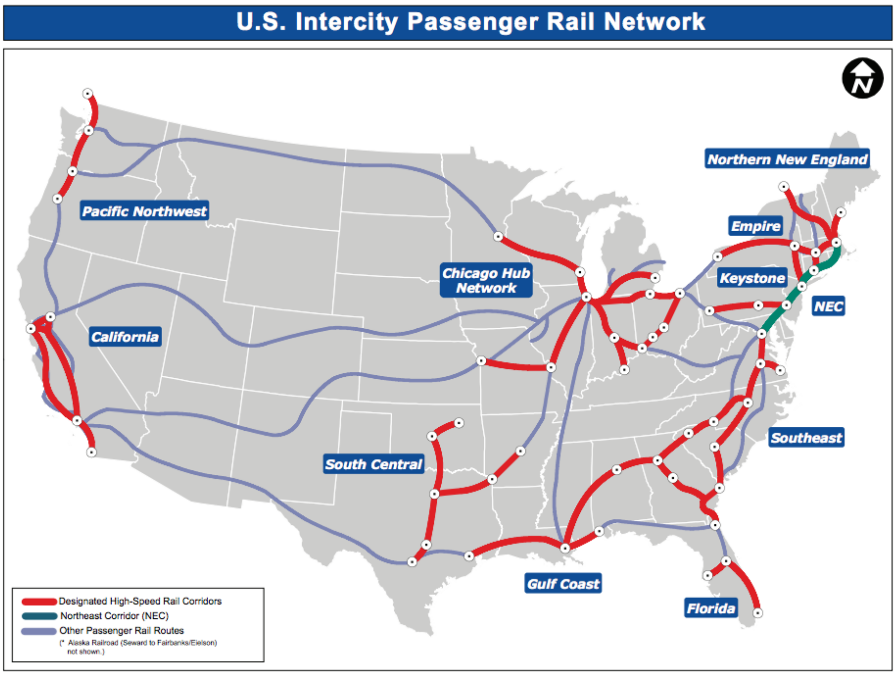

Fig.2- 1 Proposed national HSR networks in the US

(Retrieved from [6])

Fig.2- 2 The Proposed HSR Route from Tampa to Orlando in Florida

(Retrieved from [8])

On the other hand, there are several think tanks with different ideologies that enthusiastically support the HSR projects. In its report [13], Lincoln Institute of Land Policy pointed out several advantages of HSR such as enhanced mobility, economic benefits, environmental and safety improvements and emphasizes the importance of HSR having dedicated railroad completely separated from other freight and local railways. To realize the plan, it claimed that the federal government should increase national involvement in each project and especially prioritize the Northeast Corridor (NEC), connecting Washington D.C., Philadelphia, New York City and Boston, and the California Corridor by strong management and financial support. American Public Transportation Association (APTA), which consists of large number of public transportation operators, also advocates HSR. It classified the opposing opinion into 8 main points and offers a counterargument for every point. It cited the idea that ". . . much of the opposition to rail projects appears to stem not from economic arguments, but from fundamental cultural values on what 'American' transportation should be." [3] Therefore it claimed that we should start a national debate and make a judgment from the viewpoint of economic analysis [3]. In the results of random phone interviews supported by the APTA in 2015, more than two thirds of American people support the HSR project because "[t]hey are likely to use High Speed Train service for business or leisure travel, if such a mode of transportation were available to them today." [14] These claims are based on qualitative evidence, so that it cannot be denied that they lack scientific evidence or concrete facts.

2.3 Public High Speed Rail Projects

After about 8 years have passed since the national projects were announced officially, parts of several HSRs and substitutes for HSR are now under construction, even though the projects are making slow headway. For example, California High Speed Rail Authority (CHSRA) leads the California High Speed Rail Project, eventually extending from Sacramento to San Diego having a total of 800 miles with 24 train stations, as shown in Fig. 2-3 [15]. CHSRA will be responsible for HSR construction, maintenance, and operation after its commencement. It is supposed to connect two large cities, San Francisco and Los Angeles, within 2 hours and 40 minutes at the highest speed of 220 mph. Before the Obama administration implemented the national policy, in 2008, the bill issuing $9 billion state bonds for the project was accepted by a state referendum as a scheme for public funding. However, some counties and local governments tried to stop the project by raising a lawsuit against CHSRA. Finally, construction started in January 2015 after 2 years of delay. At the moment, HSR is supposed to start partial operation in 2029, which is 3 years later than the initial plan [15].

In Illinois, as a first step of the Chicago Hub Network of passenger rails, the upgrade of the local line between Chicago, IL and St. Louis, MO is making progress now, as shown in Fig. 2-4. It is supposed to connect these two cities 284 miles away [16]. In addition to the $1.2 billion subsidies from the federal government, the Illinois Capital Bill will gather $ 400 million for its construction cost, so that this is a completely public project supported by public funding. To suppress the construction cost, the state plans to make double tracks on the existing railroad, expand rail capacity and increase the maximum speed to 110mph. The construction started in 2010 and it is supposed to have finished by 2017. Almost the entire construction site is in Illinois, and only about 3 miles are located in Missouri from East St. Louis, IL to Saint Louis, MO. This is why the Illinois Department of Transportation leads and manages almost entire project.

Generally speaking, a huge project across several states is hard to realize when it uses public funding because we need to reach public consensus over all those regions. For example, a new HSR project in the 455-mile the Northeast Corridor (NEC) is one of those difficult projects. The Acela Express, the only existent HSR in the US running through the NEC, has been increasing the share from aviation since its launch in 2000 by AMTRAK. However, its aging infrastructure, capacity shortage as the results of increasing demand, and safety and reliability deterioration because of technological obsolescence enhanced the motivation to start the NEC FUTURE project in 2012 [17]. Even though more than 4 years have passed since then, there is no concrete progress to make a clear pathway to improve the NEC railroad. Many investigations show that the NEC is the most potentially profitable corridor for a new HSR project, but we have to overcome two challenges to make the new rail happen: “s fragmented among eight states and the District of Columbia, and all of the congestion caused by the competing intercity, commuter and freight rail services that share its infrastructure.” [18] To reach a broad agreement over the new construction of HSR by coordinating opinions among multiple stakeholders is a difficult task. Only the strong leadership and initiative by the federal government can make required progress.

Fig.2- 3 California High Speed Rail Project Overview

(Retrieved from [2])

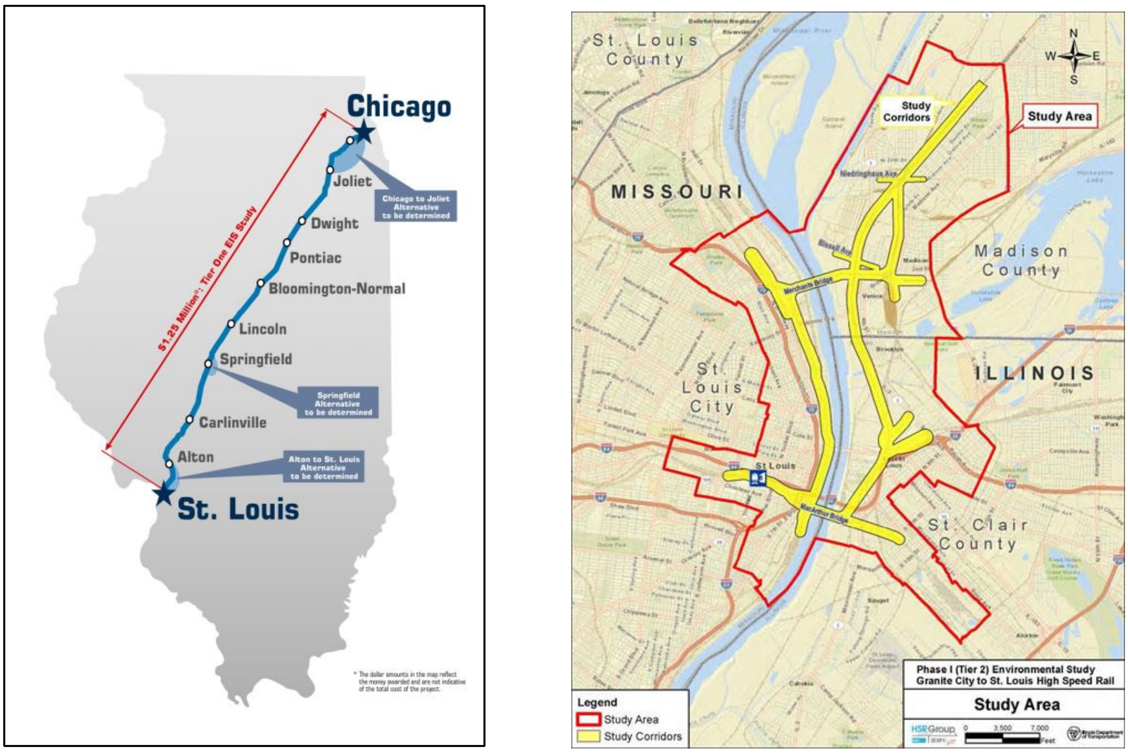

Fig.2- 4 Illinois High Speed Rail

(Retrieved from [16])

2.4 New Movements from Private Sectors

These days, some new movements to make a breakthrough for this slow progression have occurred in the private sector. If private entities take responsibility for construction and operation not using public funding sources, it could make dramatically rapid progress. For example, in the state of Florida, after the abandonment of an HSR project in 2010, a private freight rail company called All Aboard Florida has moved on a new rail project, which plans to create as fast a train as the Acela Express in the NEC running about 125 mph [19]. Its operation is limited to some extent because it intends to share existing rail lines with fright rail lines by upgrading them. By doing so, it can reduce the construction cost and can afford to do the project only with private sector. It started the construction of upgraded new rail lines in 2014, and it is supposed to commence its operation of short segment of entire line, from Miami to West Palm Beach, by the end of 2017 [19]. In future, it is scheduled to be extended up to Orlando, as shown in Fig. 2-5. Using the existing equipment to reduce the initial cost, this is a good example to see how a private entity can make rapid progress in the field.

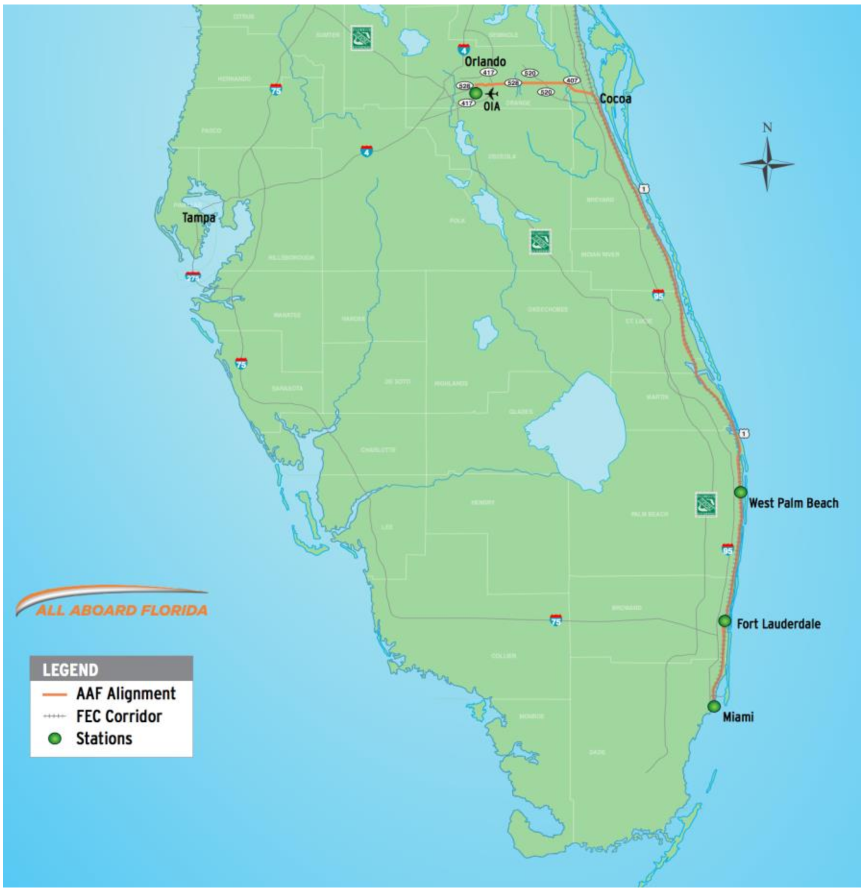

Fig.2- 5 The proposed Florida HSR planned route

(Retrieved from [19])

2.5 Conclusion

In this section, we give an overview of HSR projects in the US under challenging environment. As firstly discussed above, what have delayed the US HSR projects are mainly political conflicts, not technical reasons. This is because of the difficulties of making agreements in the federal system and also fierce ideological opposition to use large amount of public funding for the projects.

However, we also show the possibility of new movements from the private sector to make a breakthrough for the slow progression of publicly funded HSR projects. In the next chapter, we introduce the proposed Texas HSR project as one of these promising HSR projects.

Chapter 3: Overview of the Texas High Speed Rail Project

The Texas High Speed Rail Project will be the first HSR project in the world that is supported by no US government funding and done by private companies. In this chapter, we look at overall circumstances and various aspects related to the Texas project.

3.1 Background

The state of Texas has the second largest population, over 27 million in 2015, next to California in the US [20] and the annual growth rate is very high, over 1.80% in 2010, 2014, and 2015 as shown in Fig. 3-1. Comparing the demographics of the census data, the population in the state increased from 25.24 million to 27.45 million during 2010-2015 [21]. Projections of population growth from 2010 to 2050 are shown in Fig. 3-2. Three lines show the results of projection of scenario 1.0, 0.5 and 0.0. According to the Texas Demographic Center [22], the result of Scenario 1.0 is estimated assuming that the demographic trends (race/ethnicity, age, sex etc.) of net migration rates in 2000-2010 continue until 2050. Because "[t]he 2000 to 2010 period was characterized by rapid growth in many areas of the state" and "thus this scenario is presented here as a high growth alternative." Scenario 0.5 is estimated by half of net migration rates in 2000-2010, and Scenario 0.0 is estimated as net migration is zero [23].

According to the report of the Texas Department of Transportation (Texas DOT) [24], the population growth has been expected to be high especially in 4 major urban areas: Dallas/Fort Worth, Houston, Austin, and San Antonio as shown in Fig. 3-3 and 3-4. According to another report [25], the population is highly concentrated on the eastern areas in Texas, which include three of the most ten populous metropolitan areas in the US, Dallas-Fort Worth, Houston, and San Antonio. The population in the Dallas/Fort Worth area, for example, was about 5 million in 2000, but it will increase 96% in 2040 to reach 10 million. In the Houston area, the population, which was 4.7 million in 2000, will reach 8.4 million in 2040 with the increased rate of 78% as well. As the population grows, traveling has increased dramatically, and so existing transportation networks based on highway and air between two cities would not meet the transportation demand. The Texas DOT identifies this corridor between Houston and Dallas as a place that needs construction of an improved rail system including brand-new HSR as a new transportation mode. Currently, Interstate Highway I-45 has been the major route between the two regions about 250 miles apart.

year	population	annual growth rate
2010	25,244,363	1.86%
2011	25,654,464	1.62%
2012	26,089,741	1.70%
2013	26,500,674	1.58%
2014	26,979,078	1.81%
2015	27,469,114	1.82%

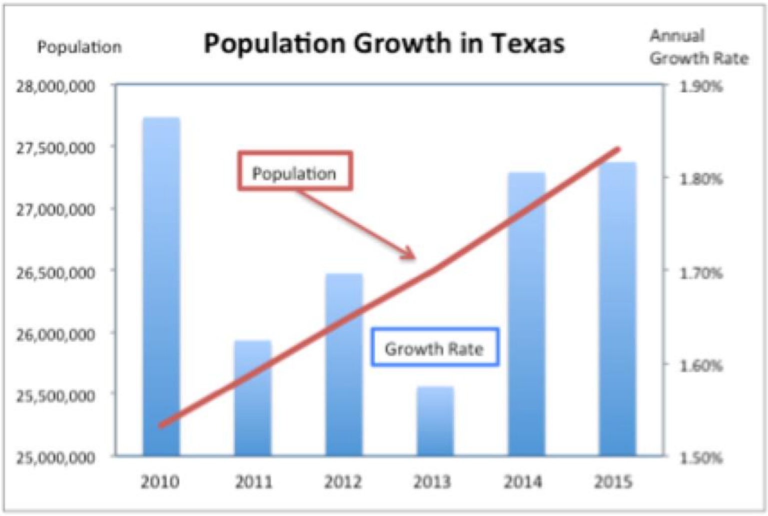

Fig.3- 1 Population growth in Texas

(Data Source: United States Bureau of Census [21])

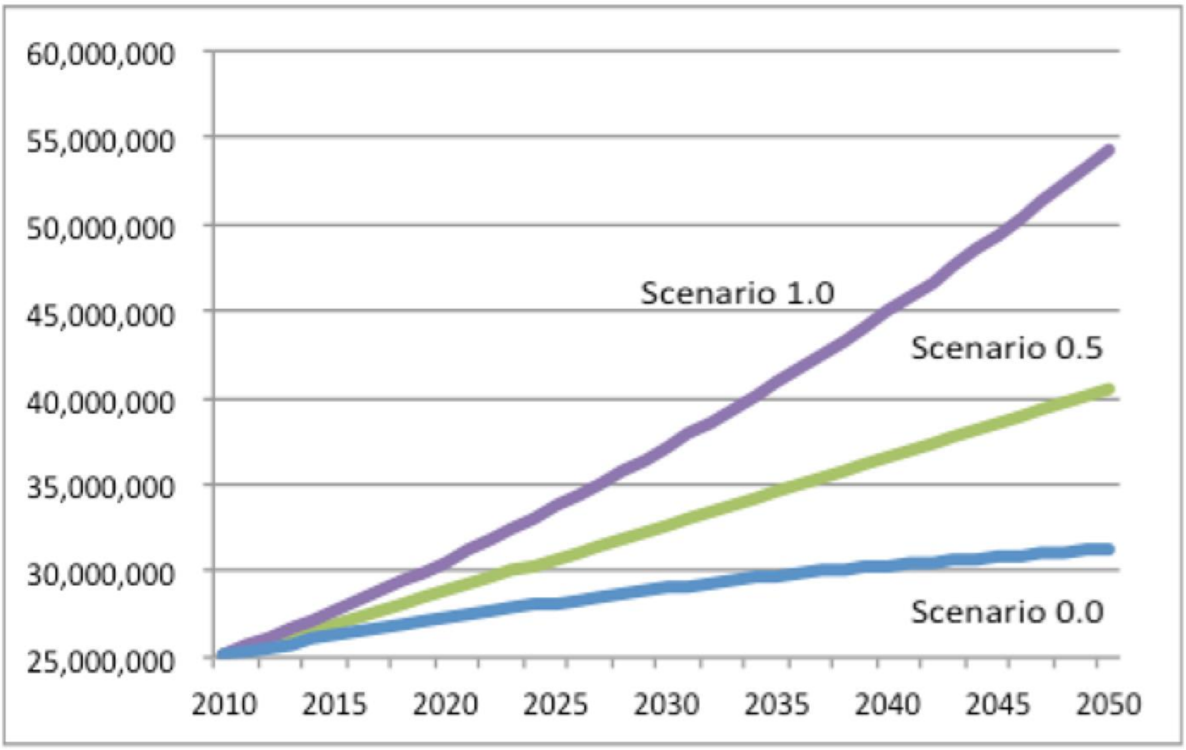

Fig.3- 2 Projections of Population Growth under Three Migration Scenarios

(Data Source: Texas Demographic Center [22] [23])

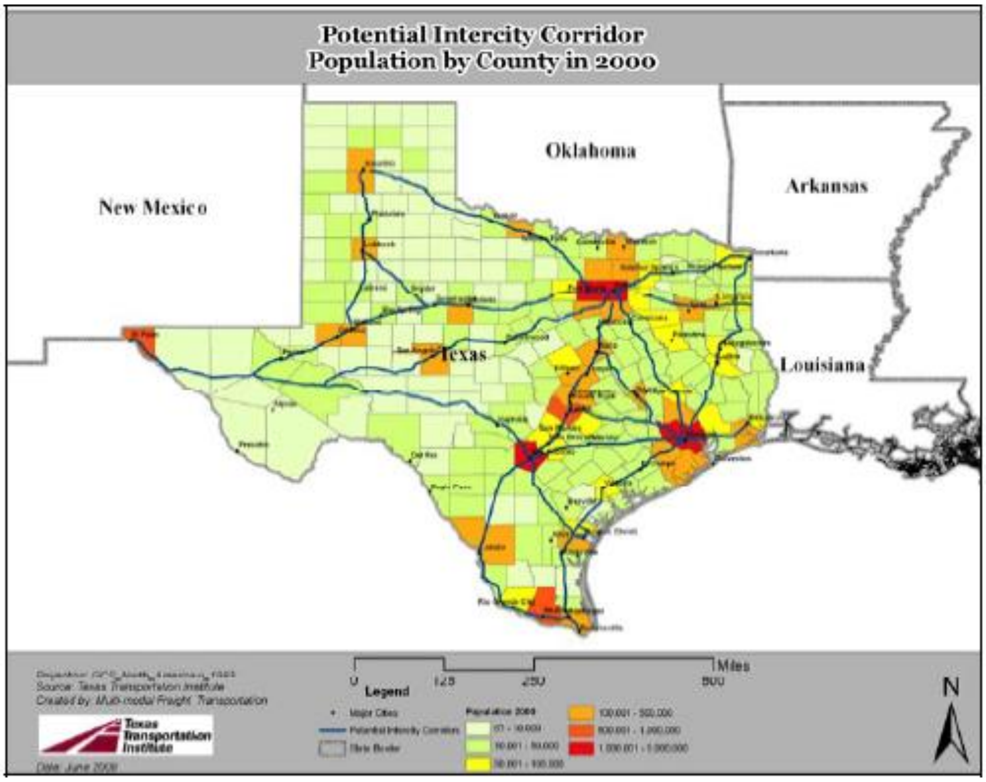

Fig.3- 3 Projected Population in each county in Texas, 2000

(Retrieved from [24])

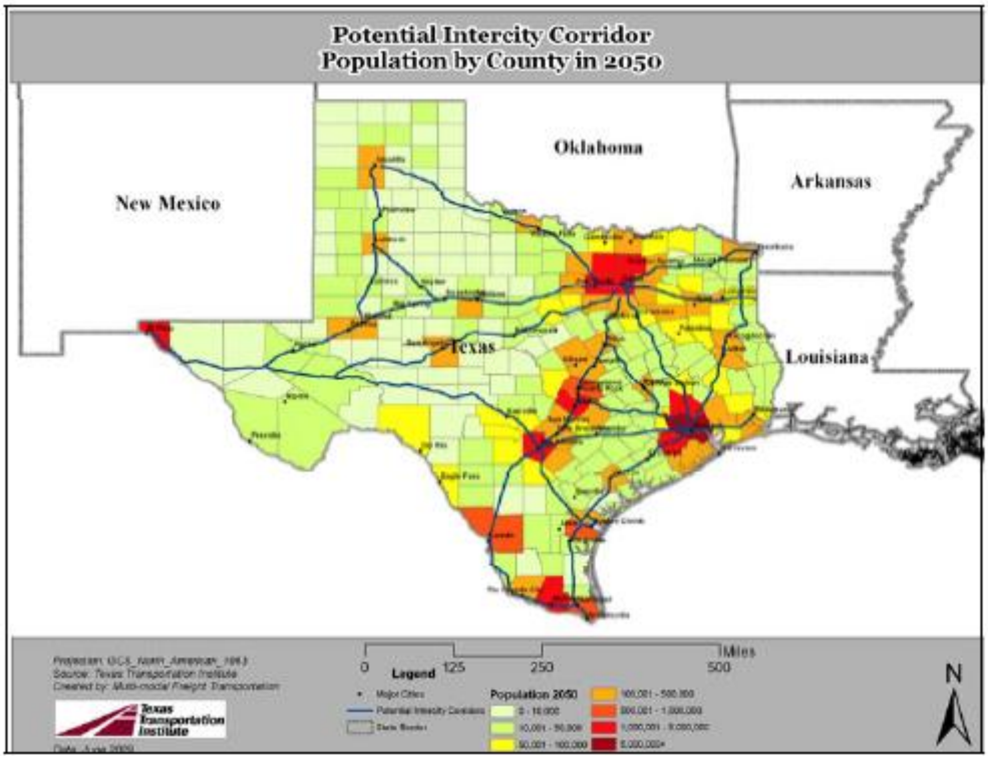

Fig.3- 4 Projected Population in each county in Texas, 2050

(Retrieved from [24])

Over recent years, increasing car use has caused serious environmental problems including noise, congestion and air pollution especially in large cities all over the US. As shown in Fig 3-5, the Houston and Dallas areas are two of the most congested areas in the US, because the expansion of main roads could not keep up with the rapid population growth [26]. Travel time between these two cities by driving a private car will be expected to increase to over 6 hours in 2050 from the current 3.5 hours, due to the heavy congestion [27]

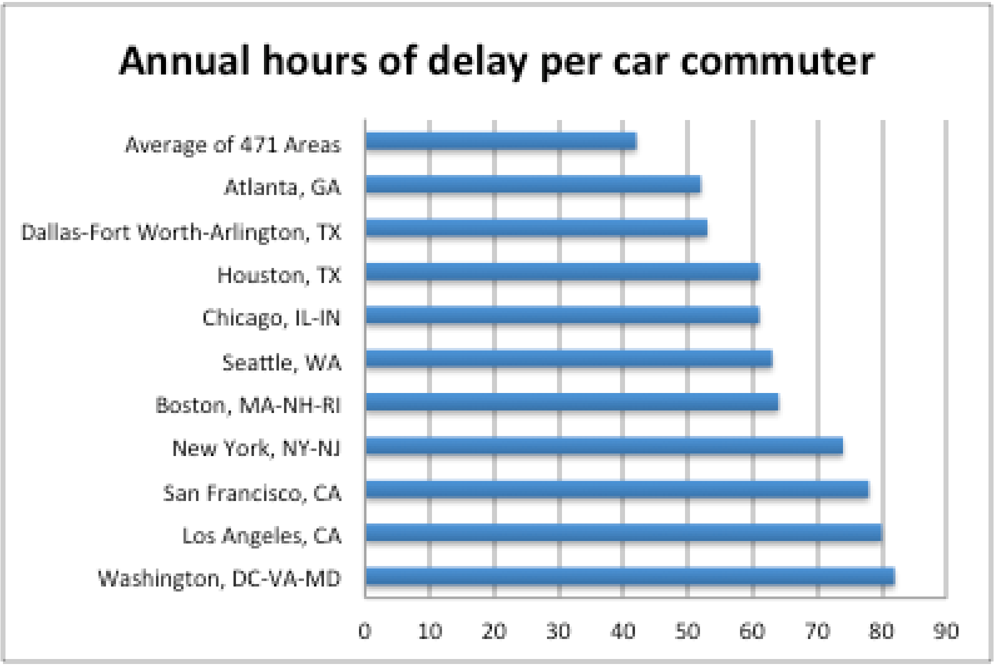

Fig.3- 5 11 most congested cities in the US (2014)

(Data Source [26]: U.S.DOT Bureau of Transportation Statistics)

The amount of air travel between the two areas is also very large. In the Dallas/Fort Worth area, there are two main airports, Dallas/Fort Worth International Airport (DFW) as a huge hub and Dallas Love Field Airport (DAL). The Houston area has George Bush Intercontinental Airport (IAH) as a hub and William P. Hobby Airport (HOU). In 2006, when the report was written by Texas DOT, average flight numbers reached 130 per day, and the average load factor exceeded 70% [24]. The number of passengers taking 65-minute flights between these two cities adds up to over 1.6 million each year [24]. Considering the future growth of projected transportation demand, it is said that flying extra planes by itself cannot sufficiently accommodate all of the demand expansion between the two cities.

When we think about rail networks, Texas has two intercity networks operated by AMTRAK and connecting several large cities as shown in Fig. 3-6. One is the Texas Eagle train, which originates in Chicago, IL, goes via St. Louis, MO, and through Texas from Dallas, Fort Worth, Austin, and San Antonio, to finally reach Arizona, and Los Angeles, CA. The other one is the Sunset Limited train running from East to West, starting in New Orleans, LA, going via Houston, TX, and reaching San Antonio, TX. The numbers of both trains and ridership are very limited. According to the data from AMTRAK, the ridership of the Texas Eagle in 2014 fiscal year was about 310,000, falling 8.8% from the previous year, and the ridership of the Sunset Limited was only 105,000, increasing 2.1% from the previous year [28]. The impacts of these trains are not high, but AMTRAK claimed that overall ridership and revenue from those lines had been increasing constantly due to its investment in facilities. AMTRAK is likely to protest fiercely when a new project tries to come into the market competing with its existing lines. In contrast, there is no existing rail line between Dallas and Houston, and so a new entity could enter the market with less political conflict than in other places in the U.S. such as the NEC.

3.2 Summary of the Texas High Speed Rail Project [30]

The Texas HSR is a rail project that will connect the 240-mile corridor from Houston to Dallas in Texas. The maximum speed of the train will be 205 miles per hour, and it will make it possible to connect these two cities within less than 90 minutes. This project is based on the Shinkansen bullet train technology provided by Central Japan Railway (CJR) Company, which is one of the main private HSR operators in Japan. This technology uses the right-of-way that is a "fully sealed corridor with grade-separated crossings," and dedicated only for passenger HSR services [30]. As the main purpose of this HSR line is to construct a single-link system between two large cities, stations will simply be constructed inside or adjacent to both cities, and only one intermediate station will be constructed near Shiro Station area if the Utility corridor is adopted. The Utility corridor is one of the candidate corridors and most promising one, as TCP claims in the report [31]. If any constraint will emerge for the Utility Corridor, then the UPRR Corridor could be adopted as one of the alternatives, and the intermediate station will be constructed adjacent to Bryan/College station area, which has "importance as a center for higher education and premier bio-medical and other services." [25] Several main routes are selected by Federal Railroad Administration (FRA) as candidates of future HSR corridor, and all of them are based on the proposal of the private entity mentioned in the next part. These potential corridors are shown in Fig. 3-7.

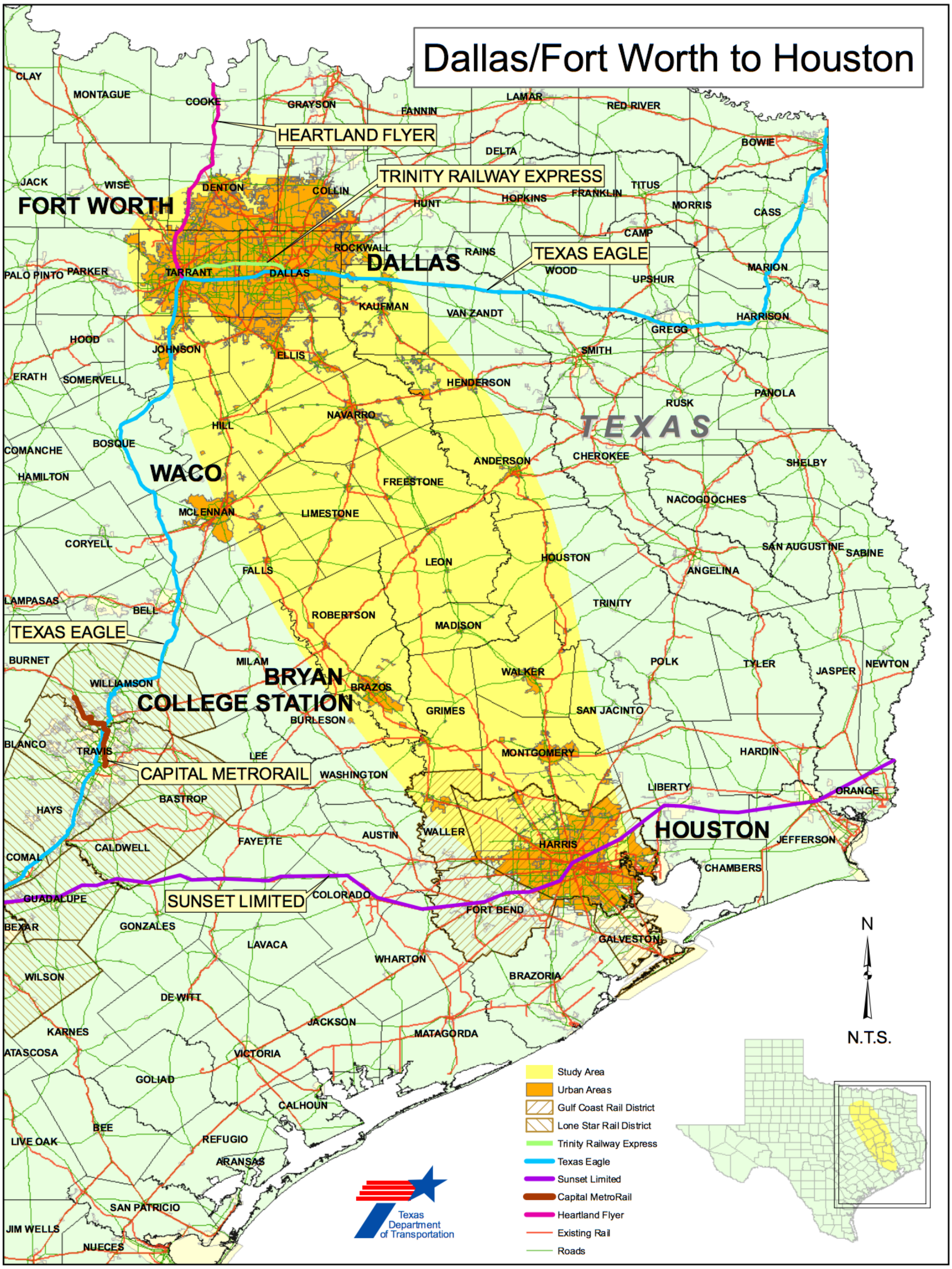

Fig.3- 6 Existing railway networks in Texas

(Retrieved from [29])

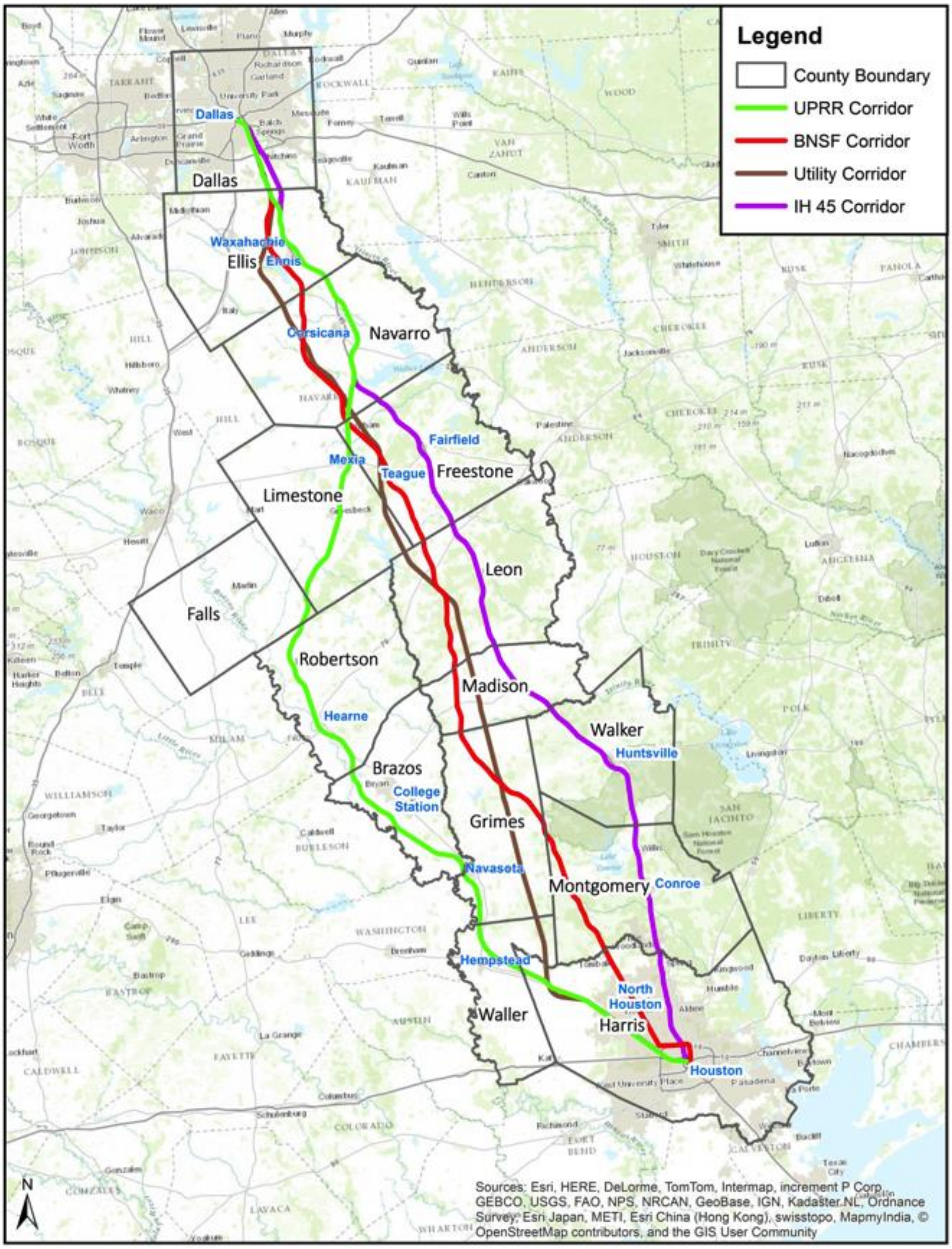

Fig.3- 7 Proposed routes of the Texas HSR project

(Retrieved from [31])

3.3 Main Actors of the Project

Texas Central Railway (TCR), the first promoter and an antecedent company of Texas Central Partners (TCP), conducted its promotion activities and base investigation from 2009 to 2014 (Phase1: Research & Promotion). Then, in 2014, when a good prospect was seen to some extent, TCP was established and it started feasibility studies including a business plan and an environmental impact assessment (Phase2: Development). Continuing several-year promotion activities and gathering funding, TCP will be a promoter in HSR's construction phase, and also TCP will be an owner of the HSR after its commencement. Now, TCP, as a for-profit entity backed by only private investment, serves as a main developer of the project. TCP has raised funding from private investors mainly for all of the initial cost, including land procurement cost, construction cost of railways, rolling stocks and other miscellaneous fee, estimated to be more than $10.9 billion [32]. If this funding process goes well quickly, then TCP will start construction in the end of 2017, and TCP will start HSR operation in 2022 (Phase3: Construction & Operation). Dallas to Houston Contractors (DHC), a joint venture of two large construction companies, Archer Western Contractors Ltd. and Spain-based Ferrovial Agroman, has already done free pre-construction cooperation worth $130 million, and DHC will be appointed as a construction company of this huge Texas-based project [33].

3.4 Key Technology and Selection of the Route [34]

As currently planned, the Texas High Speed Rail project will be constructed based on the Japanese bullet train systems, called Shinkansen, that CJR proposes to deploy for oversea projects. The technology adopted for the project is called "N-700 I Bullet" HSR system, which is now used in Tokaido Shinkansen connecting the three largest metropolitan areas, Tokyo, Nagoya and Osaka, since 1964. This system is established based on "Crash Avoidance Principles" [34]; using a fully-dedicated line for passenger HSR service, which is physically separated from surrounding areas as shown in Fig. 3-9; and Automatic Train Control system that prevents crashes between trains by positively controlling distances between each train and prevents speed excess by automatic braking system, thus it has less need to make the train cars robust to protect passengers from anticipated crash. These principles enable rolling stocks to be lighter, and thus compact, than other ones that require impact resistance performance in the U.S. and other European countries. In this way, the Shinkansen system has great advantages in high energy efficiency and low physical burden for its rails. The lighter rolling stocks can make bridges less robust therefore more compact due to reduced physical burdens on them. The compact cross-sectional structure of the rolling stocks can also make tunnels more compact [34]. Thus, Shinkansen system makes available less construction and maintenance cost than other rail systems in the world do. To implement the full system, TCP is supported by High-Speed-Railway Technology Consulting Corporation (HTec), which is the wholly owned subsidiary of CJR established in May 2016. Although these safety standards are not applicable in an ordinary railroad under the Federal Railroad Administration's (FRA) regulation, TCP has already applied for an exception under the FRA's special regulations called Rules of Particular Applicability (RPA), which are "[r]egulations that apply to a specific railroad or a specific type of operation" [35]. TCP has also submitted an Environmental Impact Assessment (EIA) of anticipated route selections according to the National Environmental Policy Act (NEPA). TCP will soon start to negotiate with landowners to condemn the land for the use of the right-of-way. In case some of the negotiations do not go well, the use of Eminent Domain act of Texas, that is applicable for the infrastructure project for the public good and allows TCP to condemn the land instead of offering reasonable compensation, will be under consideration.

In the analytical report based on NEPA [30], the Utility Corridor running near existing high-voltage electrical transmission lines is identified as the most suitable place for HSR construction because the corridor is "relatively straight, existing long, linear infrastructure easements between Dallas and Houston" and enables the HSR to perform at "high speed" due to the less curved line, which is a perfect fit for a right-of-way of HSR. Based on the results, TCP published two additional analyses [36] [37] in 2015, and claimed that the Utility Corridor is the only reasonable route for them to construct dedicated trucks completely sealed by structures, considering construction cost, secured easement, rail linearity and access to the power transmitted by the high-voltage line [yourhoustonnews.com]. Besides these reports, TCP also published another one to determine where it should construct the terminal stations in the Dallas and Houston areas [36]. In this report, comprehensively considering construction and land acquisition cost, ridership estimation, constructability, environmental impact, and the possibility of residential and industrial development, TCP determined the suitable sites to construct the terminals in both Dallas and Houston. It said that there is a tradeoff between accessibility improvements by entering into the center of the business district and the increase of land-acquisition cost and difficulties of construction. In Dallas, existing light rail and local bus networks are well developed, thus high ridership will be estimated when the terminal station comes into the downtown in the city center and secures good accessibility to those pubic transit networks. TCP estimates that if it can attract sufficient number of business passengers from the downtown area, revenue will increase enough to cover all of the sharp increase in the initial cost to construct the terminal adjacent to the business district. On the other hand, Houston is much more sprawling than Dallas, and considering its wide-spread city structure and less-developed public transportation networks, TCP proposes to construct the terminal in a suburban area apart from Houston downtown. To secure the accessibility, TCP has a plan to construct large parking zones near the Houston station to accommodate a sufficient number of cars and to promote park & ride usage of the HSR. Based on these proposals of route selections and terminal places, the FRA is now preparing a draft of an Environmental Impact Statement, and in the late 2016 it will be made available to public notice.

TCP publicly announced its planned service as follows [38]:

・Composition of the train: 8 cars and 400-passenger seats
・Operation hours: 5:30am – 11:30pm (departure in both terminals)
・Headways: 30 minutes (busy hour in morning and evening), 1 hour (other)
・Structure: Running on the right-of –way (ROW) with 76-200 feet width having two-track railroads (Fig.3-8 shows cross-sectional view of fully sealed dedicated tracks)
・System: Fully-dedicated for passenger HSR without any shared service with conventional rail or freight rail, closed system physically separated from surrounding areas without crossing

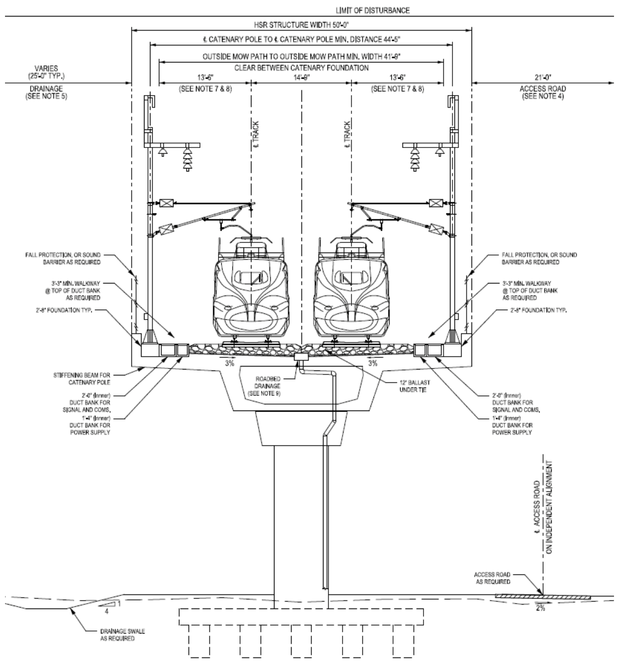

Fig.3- 8 Cross-sectional view of fully sealed dedicated tracks

(Retrieved from [37])

3.5 Challenges

3.5.1 Procurement of Very Large Initial Cost

First important challenge that the private entity has to face is to procure vast investment cost, mainly used for land acquisition, rail and other facility construction, and rolling-stocks production cost. TCP spent $40 million in promotion activities and base investigation in phase 1 (Research & Promotion). In the second phase (Development), TCP needs an additional $400 million to conduct several environmental impact assessments and detailed business planning before the construction itself begins. Before entering upon the third phase (Construction and Operation), it is estimated that TCP has to gather about $10 billion for a direct initial investment [39]. In 2015, TCP officially pronounced that it had raised $75 million from private investors as the “first fund raising.” [40] Those $75 million will be spent on environmental impact analyses, study processes necessary to apply RPA to the FRA, and detailed ridership analyses by consulting firms [27].

TCP asked Dallas to Houston Contractors (DHC) to conduct and bear the financial burden for the pre-construction investigation, $130 million expenses, in return for the contract on future construction of this huge infrastructure [41]. In 2015, The Japan Overseas Infrastructure Investment Corporation for Transport and Urban Development (JOIN), which is the “first and only government-private sponsored fund in Japan” whose main objective is to aid Japanese infrastructure companies with overseas project [42]. JOIN decided to invest $40 million for the Texas HSR project to promote the first export case of the Shinkansen technology to the world. Now, TCP continues its work on fundraising and indicates that it has contacted Texas-Based equity funds and real estate developers to procure $185 million by the end of 2016. TCP is now aiming to start the construction process by the end of 2017. To secure investment from the local investors, TCP asserts publicly that this project will yield benefits to Texas. It estimates that total economic benefits will reach over $36.3 billion based on the initial $10 billion direct investment of TCP from 2015 to 2040. After the HSR starts its operation, TCP is estimated to pay about $2.5 billion in tax of the state government and local municipalities. Over 1,0000 new jobs will be created annually during 4 years of construction, and more than 1,000 permanent jobs will be created for the HSR operation and maintenance [39]. TCP claims that people will have benefit from the advantages of “Ripple-Effect across Texas,” including job creation, tax revenue and a real-estate business resulting from the project such as a development of new residential/commercial areas. These public appeals for the local understandings are essential to ensure the smooth project implementation.

3.5.2 Opposition from Landowners and Inhabitants

Municipalities, such as Grimes County, and some of the residents and landowners living along the planned route are opposed to the construction of the HSR line, because these midpoint areas have little access to the new station and so they think they have few benefits from the project [43]. TCP will conduct individual negotiations with these landowners to compensate for the land acquisition, but if these negotiations fail, TCP might think of using the Eminent Domain as a last resort to solve the problem. The Eminent Domain is based on the Texas Constitution[1], which prescribes "a right of federal or state government within its jurisdiction to expropriate landowners from their land ownership for some project for [the] 'public good,' such as railroad, by compensating them for fair market price of the land." [44] The issue concerning the Eminent Domain is whether a private rail project has the authority to condemn private property. As a first step, in May 2016, TCP petitioned to confirm whether the HSR project was under the jurisdiction of Surface Transportation Board (STB), which is the board under the Federal DOT and that settles any interstate surface-transportations disputes. If the Texas HSR project can be seen as a part of the National HSR network, then it falls under the jurisdiction of the STB, and TCP needs to obtain an approval for its construction. The STB concluded that the Texas HSR project is not connected to other HSR networks from the view point of technical differences and stations' location, and it will be operated privately only in the state. Therefore, the STB has no authority to make any regulations on the project. Thus, the rail project must be admitted by the Texas government as for the "public good" to apply the Eminent Domain and condemn the land if landowners will not agree.

3.5.3 Technical Barrier

As mentioned in section 2.2.2, the implementation of the Japanese "Shinkansen" technology requires dedicated rail lines for passenger trains on right-of-way corridors that are fully sealed and separated from outside areas, and Automatic Train Control (ATC) systems to avoid crashes between trains. Its high operation accuracy is made available with the use of Centralized Traffic Control systems to control all operating trains in one control center. Its crash-avoidance principle enables

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[1] The Texas Government Code prescribes as follows [44]:

A governmental or private entity may not take private property through the use of eminent domain if the taking: (1) confers a private benefit on a particular private party through the use of the property; (2) is for a public use that is merely a pretext to confer a private benefit on a particular private party; (3) is for economic development purposes, unless the economic development is a secondary purpose resulting from municipal community development or municipal urban renewal activities to eliminate an existing affirmative harm on society from slum or blighted areas under:

rolling stocks to be light and energy efficient, and it also has an advantage of having smaller and less expensive structures supporting lightweight cars. On the other hand, in the U.S., the FRA requires the rolling stocks to have high crashworthiness in case of possible collision accidents, and thus the weight of the train cars get much heavier than Japanese ones. As a result, construction and maintenance costs of civil-engineering structures get higher, and energy efficiency gets worse. From the technical perspective, these two safety standards are totally different. Thus, TCP needs to apply for an exemption from the Rules of General Applicability (RGA) [35]. Now, TCP is asking the FRA for the Rule of Particular Applicability (RPA), which is the special treatment of regulations applicable to specific HSR lines in the US. TCP is also cooperating with the FRA to conduct an Environmental Impact Assessment according to the National Environmental Policy Act (NEPA) [31].

3.5.4 High Ratio of Car Ownership and its Trend

The general HSR is implemented as a transportation method to connect several large cities. Their centers are usually densely populated areas, and so people should have a merit of using public mass transit system to avoid heavy congestion. As a long-term trend in the US, the rate of households who have no private car has increased in the large cities since 2007 [45]. However, as shown in Fig. 3-10, this trend cannot be seen in Texas. The percentage of household without a private vehicle in Texas tends to be the same or even increase slightly since 2007. The absolute values of those percentages in large Texas cities are considerably higher than those in other regions such as New York, Philadelphia, Chicago and so on. As the Reason Foundation mentioned, car travel is deeply included in the economy and geography of Texas. “Simply building new high speed rail lines will do nothing to change that,” they said [12]. From this perspective, the HSR operator should answer the tough question, “Whether will a new HSR be accepted as a reliable transportation method instead of private car?”

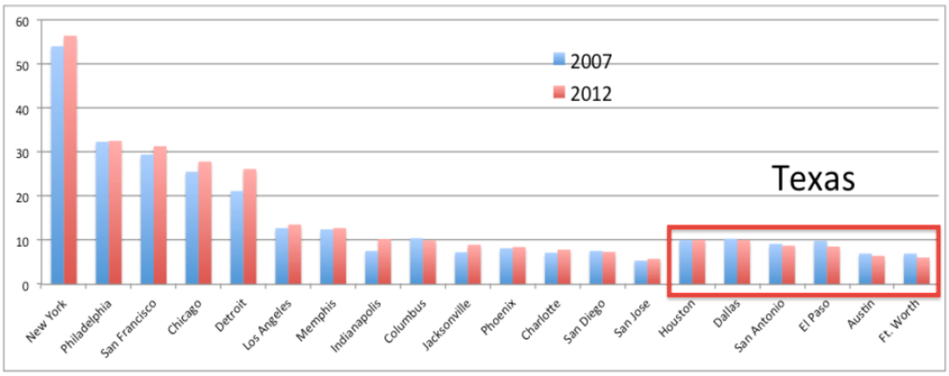


Fig.3- 9 Percentage of Households without a vehicle in the 20 largest cities

2007 and 2012 (Data Source: University of Michigan [45])

3.5.5 Profitability

The most distinctive feature of this Texas HSR project is that its construction and operation cost will be covered only without US government funding. There is no modern HSR project built up from the beginning and operated only by the private sector without any public funding. In general, the profit model of infrastructure businesses, such as railroad construction, is based on long-term strategy to recover its heavy initial investment cost within several decades [46]. Thus, there is a high barrier-to entry for the private sector. New schemes such as the Public-Private Partnership (PPP), concession system, and vertically separated model are attempts to reduce the financial risk of private actors. Japanese Shinkansen networks and the Taiwan HSR project are considered to be successful examples of these schemes. The PPP is also expected to be a suitable system for HSR projects in the US, such as an example for the California HSR project [47][48].

However, the Texas HSR project will be promoted without any public financial aid. To be successful, it has to keep a high standard of ridership by providing customers with high-quality transportation service, because the revenue will come mainly from passenger fares. It has to pile up the profit and use some profit for new capital investment that is gradually improved for several decades, like Japanese private rail companies have done for the last several decades [49]. This business model can make the HSR project profitable, and the project will contribute to public interests by providing revolutionary transportation methods at the same time. On the other hand, it is difficult to conduct an accurate demand forecast of ridership and modal split after the implementation of the HSR, because such a forecast includes many uncertainties, such as the economic situation, people's tendency for mode choices and changes of urban structure. TCP announced that this project will yield total economic benefits of over $36.3 billion from 2015 to 2040 [32], but detailed cost/benefit analysis and profitability forecast are not published yet. The opponents of the HSR project usually claim that the ridership is overestimated, and the government will financially rescue the project in the future by spending public tax revenues on it. Conventional demand analysis cannot predict precisely the demand change of intercity transportation mode in a time series.

3.6 Conclusions and Questions

In this chapter, we discussed various aspects of the Texas HSR project in terms of its general background, main actors, key technologies, route selection, and several challenges. When we consider the strong needs and market potential for the HSR in the regions, it seems a reasonable option to construct a new HSR line between two large cities, Houston and Dallas. However, the Texas HSR project also has varieties of uncertainties. The project is totally unprecedented because it will be the first US HSR project using foreign technology. Stakeholders and their interests are diverse. In addition, this project is funded only by private sectors. There has never been fully private-funded HSR project, which requires vast investment cost. The private entity has to collect sufficient money from private sectors, but it is a hard challenge. Another challenge is that Texas is a car-centric society; therefore it is unclear whether HSR could attract enough passengers to make the project feasible after its commencement.

To clearly identify whether this project can be successful or not, we should analyze the system from the viewpoints of technical, economic, and institutional aspects. This means to answer the following questions; what are the goals of the project for society? What can the HSR provide as a "public good"? Can profitability of the project be a public good for Texas and the US? What can the HSR do in the car-oriented society? In the next chapter, we will introduce an interdisciplinary approach of structuring the critical problems to answer these questions.

Chapter 4: Application of The CLIOS Process to the Texas HSR project

As shown in the previous chapters, considering the current circumstances surrounding the Texas HSR project, we have to take broad viewpoints of political, social, economic, environmental and engineering perspectives into account. One of the frameworks to analyze the whole complex system is the CLIOS Process, developed by Sussman et al. of Regional Transportation Planning and High Speed Rail (R/HSR) Group at MIT [4]. This process is applicable to typical problems of transportation systems whose characteristics are that highly developed technical complexity relates to political and economic matters. The CLIOS Process was applied to the Northeast Corridor in the US, where a future high-speed rail project in this area has been analyzed, for example.

To fully understand the key success factors of the Texas HSR project, it is necessary to clarify the complex structure of the physical components of the project, to identify influential relationships between stakeholders and these physical components, and to simply visualize the causal relationships of all of these factors. According to the CLIOS Process User Guide the CLIOS Process consists of the following three stages:

1. Representation of the CLIOS System structure and behavior,
2. Design, Evaluation and Selection of CLIOS System strategic alternatives, and
3. Implementation of the selected strategic alternatives.   (Retrieved from [4])

By conducting the "Representation stage" of the CLIOS Process, the objective of this chapter is to visualize the current "whole picture" of the Texas HSR project, and to clarify the characteristics of the project especially, in this application, from the viewpoint of the private sector. The CLIOS Process is the main tool to investigate the Texas HSR project in this thesis. In more detail, the results from the CLIOS Process in this chapter will be the starting point to discuss the characteristics and bundles of strategic alternatives of the HSR operator. Therefore, we will combine the CLIOS Process with several other methods shown in Chapter 5, 6, 7 and 8.

4.1 Overview of the CLIOS Process

The CLIOS Process is “a methodology for studying complex sociotechnical systems” proposed by Sussman et al. [4]. CLIOS stands for “Complex, Large-scale, Interconnected, Open, Sociotechnical Systems.” In general, a large transportation system, such as a high-speed rail system, faces a host of challenges that relate to growth of regional economy, social justice, engineering aspects, political issues and so forth. These engineering systems are composed of multiple units mutually related and having complex feedback structures. These systems have a great number of stakeholders; therefore a large impact reaches a wide range of people living inside and outside the region for a substantially long period. The main motivation of this chapter is to analyze the huge socioeconomic HSR system and to extract critical challenges it includes both apparently and inherently. Sussman et al. claimed that the CLIOS System has a “Nested Complexity” during the process of policy-making and managerial decision-making.

To apply the CLIOS Process to the Texas HSR project, illustrating a system representation of the project will be the first stage of the overall process. Fig. 4-1 shows a simple schematic diagram of the CLIOS System. The CLIOS System includes: Physical Domain, as shown in several layers of Subsystems, including Components in each of these layer; Institutional Sphere, as shown as a black spherical object, including “actors” who have a stake and influence on each Component in the Subsystems; and System boundary which segments the system inside and outside of the scope of the system. Through this stage, we can visualize the basic structure and behavior of the entire system, and we can also find “preliminary goals” which shows us how to improve the system performance. The results of the first stage will be shown in this chapter.

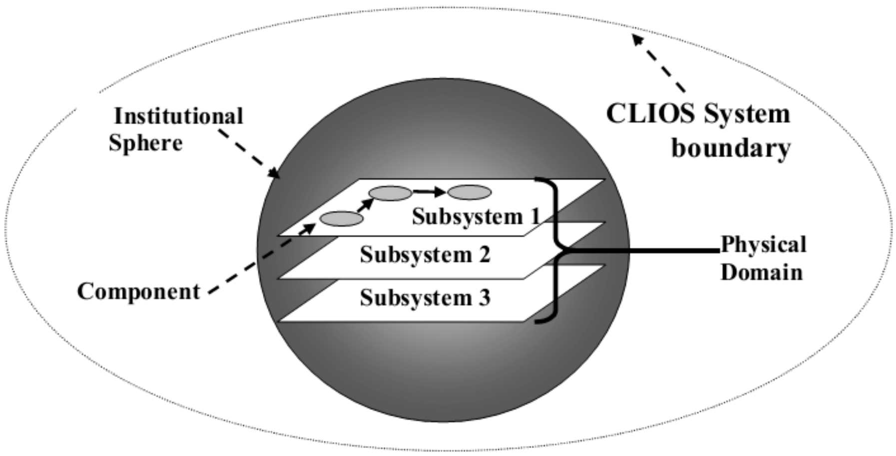


Fig.4- 1 CLIOS representation

(Retrieved from [4])

Next, in the Design, Evaluation and Selection stage, the preliminary goals we find in the first stage will be refined. As shown in A User's Guide of CLIOS Process [4], "The Representation Stage should have revealed the needs and perspectives of the stakeholders more clearly and captured the opportunities and issues of the CLIOS system under study," so now we should rethink more detailed and concrete goals of the system by asking the question, "What is the ideal state of the CLIOS System in the future?" Based on the refined goals, some sets of strategic alternatives are designed and selected to improve the Physical Domain and the Institutional Sphere we structured in the representation stage. These "Bundles of Strategic Alternatives" will be evaluated from the viewpoint of the users, such as a policy maker and a system manager. Finally, in the Implementation stage of the CLIOS Process, the bundles of strategic alternatives chosen as the solution to the system in the second stage will be implemented and evaluated in the context of political, societal, economic and technological realities. Performance improvement of the CLIOS System should be reasonably considered in a concrete time horizon and resources. This stage will provide useful proposition for policy implementation. The basic concepts of the CLIOS Process can be summarized in Table 4-1 and Table 4-2.

Fig. 4-2 shows the way that the CLIOS Process consists of 12 steps in the 3 stages. This is the basic frame of applying the methods to the specific sociotechnical system. Step 1 to Step 5 are the components of Stage 1. Step 6 to Step 9 are in Stage 2 and each of Steps 10 to 12 is a part of Stage 3. The essential steps of the representation stage in this research are Step 3, 4A and 4B, in which we create specific structures of the Physical Domain, identify the influences of the Institutional Sphere on the Domain and clarify the unique characteristics of the Texas HSR project. For Step 7, 8 and 9, we need to apply additional analytical frames to conduct both qualitative and quantitative evaluations.

As additional tools to analyze the performance of the system, various analytical methodologies will be used for specific purposes. This concept is described as follows; "The CLIOS Process can be thought of as a Christmas tree and its ornaments; the tree represents the overall process and the ornaments represent the specific tools (e.g. benefit-cost analysis, probabilistic risk assessment, system simulations, stakeholder analysis, scenario planning, design structure matrices, etc.) that one can use for specific steps in the overall process."[4] In this research, we use comparative study, market analysis and System Dynamics as an ornament of each stage. Each result will be shown in Chapter 5,6,7 and 8.

Table 4- 1 Key Ideas and Outputs of each stage in the CLIOS Process

Stage	Key Ideas	Outputs
Representation	▪ Understanding and visualizing the structure and behavior ▪ Establishing preliminary goals	System description, issue identification, goal identification, and structural representation
Design, Evaluation, and Selection	▪ Refining goals aimed at improvement of the CLIOS System ▪ Developing bundles of strategic alternatives	Identification of performance measures, identification and design of strategic alternatives, evaluation of bundles of strategic alternatives, and selection of the best performing bundle(s).
Implementation	▪ Implementing bundles of strategic alternatives ▪ Following-through – changing and monitoring the performance of the CLIOS System	Implementation strategy for strategic alternatives in the physical domain and the institutional sphere, actual implementation of alternatives, and post-implementation evaluation.

Table 4- 2 Specific questions for each Stage in the CLIOS Process

In **Stage One**, regarding the representation of the CLIOS System structure, we can ask questions such as the following:

- Can we break out the physical domain into relatively independent subsystems?
- What are the technical, economic, and social aspects of each subsystem?
- What are the main components of each identified subsystem?
- How do the physical subsystems relate to the institutional sphere?
- What are the main actor groups and who are the key individual actors/organizations on the institutional sphere that impact the physical domain or are affected by it?

Also in Stage One, regarding the representation of the behavior of the CLIOS System, we can ask:

- What is the degree and nature of the connections between subsystems?
- Are the connections weak or strong?
- Are there important feedback loops connecting subsystems?
- What insights can we gain into emergent behavior?

In both the structural and behavioral representation of the system, the analyst is guided by the issues and goals of the system, which help to bound the system and highlight the characteristics most relevant to the problem(s) motivating the analysis.

Turning to the design, evaluation, and selection in **Stage Two**, we look at both how different strategic alternatives change system performance as well as preferences of different stakeholders.

- How is performance measured for the entire CLIOS System as well as the physical subsystems?
- How do key stakeholders and decisionmakers measure or rank different types of performance?
- What are the tradeoffs among the various dimensions of performance (e.g. cost vs. performance)
- What strategic alternatives can lead to improved performance?
- How can we combine or "bundle" strategic alternatives to improve the system?
- Which bundle is selected for implementation?

Finally, reaching **Stage Three**, implementation of the CLIOS Process, we can ask the following:

- How do these performance improvements actually get implemented, if at all?
- What compromises have to be made in the name of implementation?
- What actors/organizations on the institutional sphere have an influence on the parts of the system targeted for intervention? How are these actors/organizations related to each other?
- Do the types of policies made by different organizations on the institutional sphere reinforce or counter each other?
- Under the current institutional structure, can organizations manage the system to achieve target levels of performance?

(Both tables are retrieved from [4])

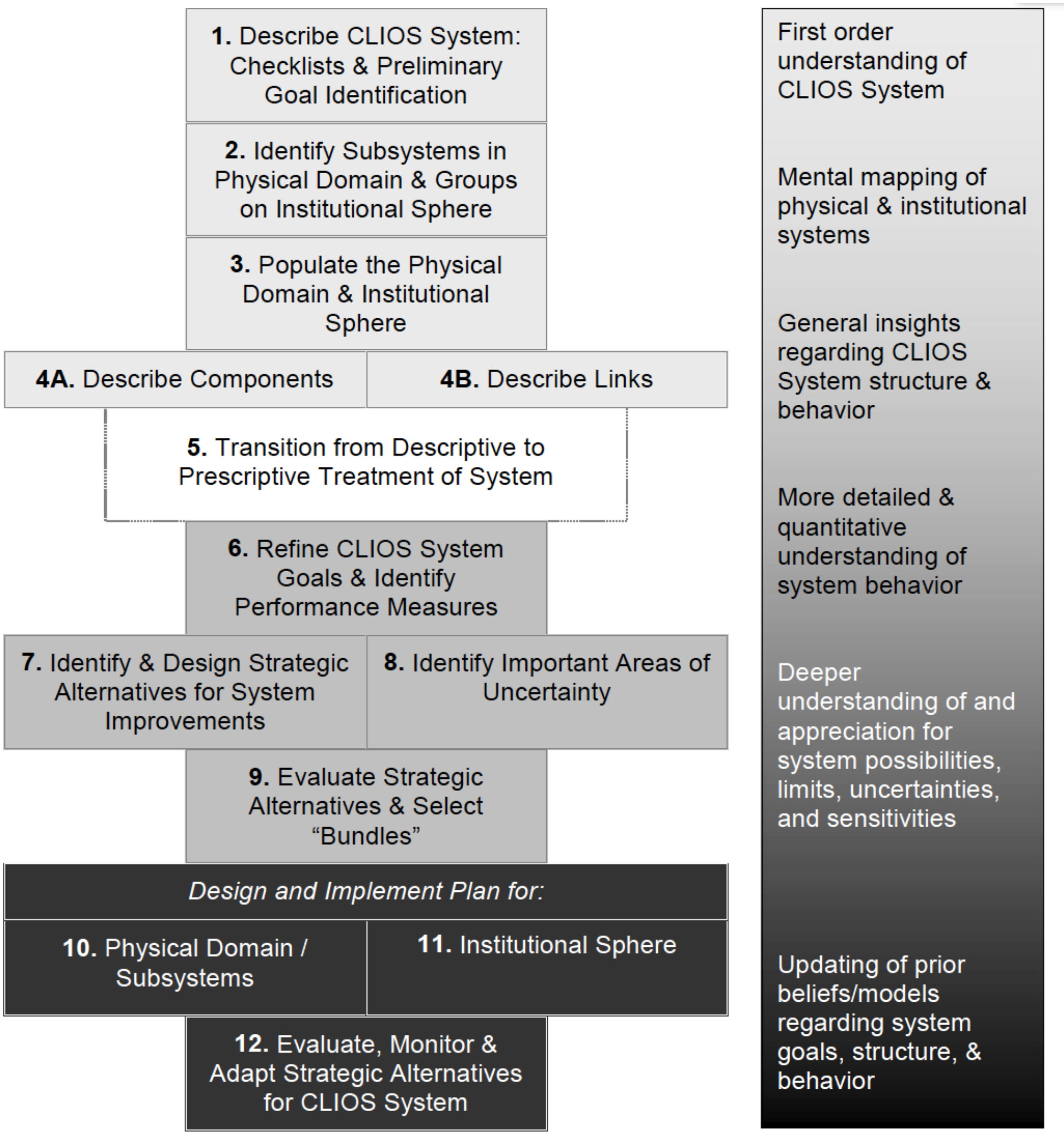


Fig.4- 2 Concept of "Christmas tree" of the entire CLIOS Process

(Retrieved from [4])

4.2 System Representation of the Texas HSR Project

The objective of this representation stage is to build up a descriptive model of the Texas HSR project and to extract some important characteristics of the project. To conduct this stage properly, we follow the typical procedure for an HSR project in the guidance of Sussman et al. [4].

4.2.1 Characteristics Checklist and Preliminary Goal Identification

For the very first step of the CLIOS Process, we begin with describing the CLIOS System by using three types of checklists to organize basic information; Characteristics Checklist; Opportunities, Issues, and Challenges; and Preliminary System Goals. This information, which clarifies managerial and policy challenges of the system, will be used in further investigation of the system in the following stages. Below, each item in the checklists is retrieved from the CLIOS User's guide [4]. As a reference, the content of the Chapter 3 will be the basic information source to complete the following checklists.

Characteristics Checklist

(a) The temporal and geographic scale of the system

The 240-mile Corridor between Dallas/Fort Worth and Houston is one of the foremost candidates for HSR implementation. Originally it is considered as part of the triangle corridor in Texas, which consists Dallas, Houston and San Antonio. This triangle corridor is also part of the national HSR network and will be connected to Chicago via St. Louis [50], as shown in Fig. 4-3.

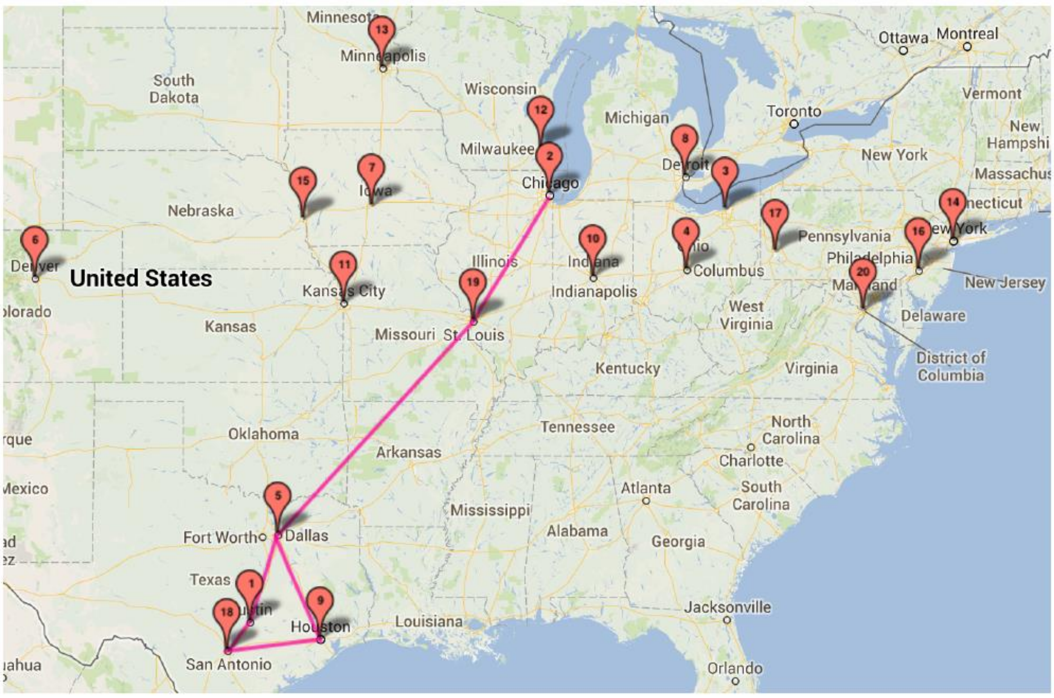


Fig.4- 3 The HSR corridors of "Texas Triangle," and its connection to St. Louis and Chicago

(Retrieved from [50])

(b) The core technologies and systems

The Texas High Speed Rail project will be constructed based on the Japanese bullet train systems. As described in Chapter3, this system is based on "Crash Avoidance Principles" [34]: using a fully-dedicated line for passenger HSR service, and Automatic Train Control system that prevents crashes between trains.

(c) The natural physical conditions that affect or are affected by the system

In general, the natural physical conditions between Dallas and Houston are suitable for constructing the HSR Right of Way (ROW). The construction costs for building the ROW, which includes two tracks, viaducts, bridges and tunnels, would be smaller in this region because of its flat and sparsely populated land structure [51]. The Utility Corridor, which is parallel to privately owned electricity power lines, is a good candidate to meet the needs of straight and flat structure of the tracks. In the report of the FRA [30], it is mentioned that more than 70% of the existing utility easements could be used for HSR ROW because it has no crossing of the utility lines. Small numbers of curves along this corridor enables TCP to operate the HSR service that connects two cities within less than 90 minutes.

(d) The key market factors

The prediction of population growth of two large cities is extremely high during 2000 to 2040 as shown in Fig. 4-4. Because HSR system requires high-populated areas to secure sufficient ridership and profitability, it is important to have at least two large cities along with the HSR line. It is generally said that an ideal role of HSR lines is to connect two or more of metropolitan areas, whose populations are at least several millions and whose central business districts are within 100 to 600 miles away as shown in Fig. 4-5 [13]. From this perspective, the 240-mile corridor between two megacities, whose population is predicted to reach over ten-million and eight-million in 2040, seems to have a good market potential.

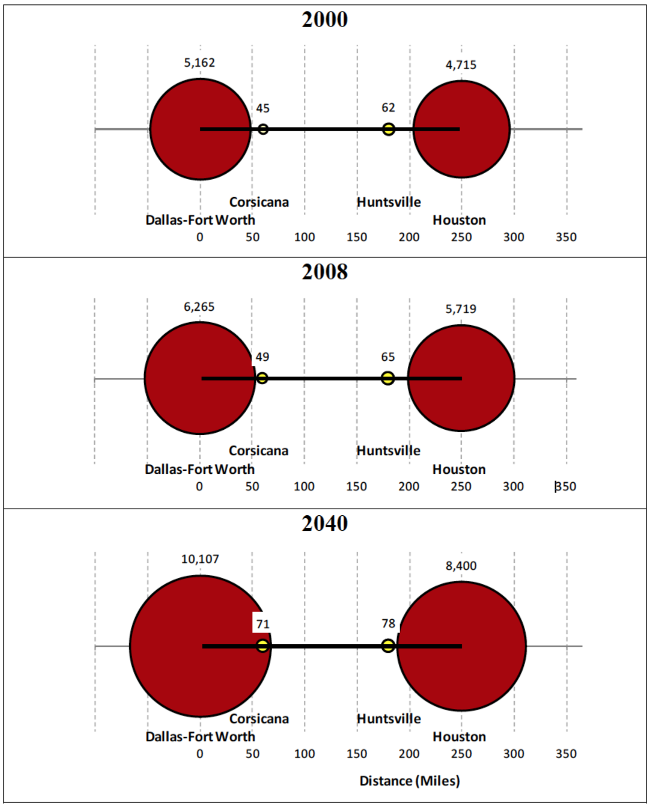


Fig.4- 4 Prediction of Dallas-Fort Worth to Houston Corridor (Population in thousands)

(Retrieved from [25])

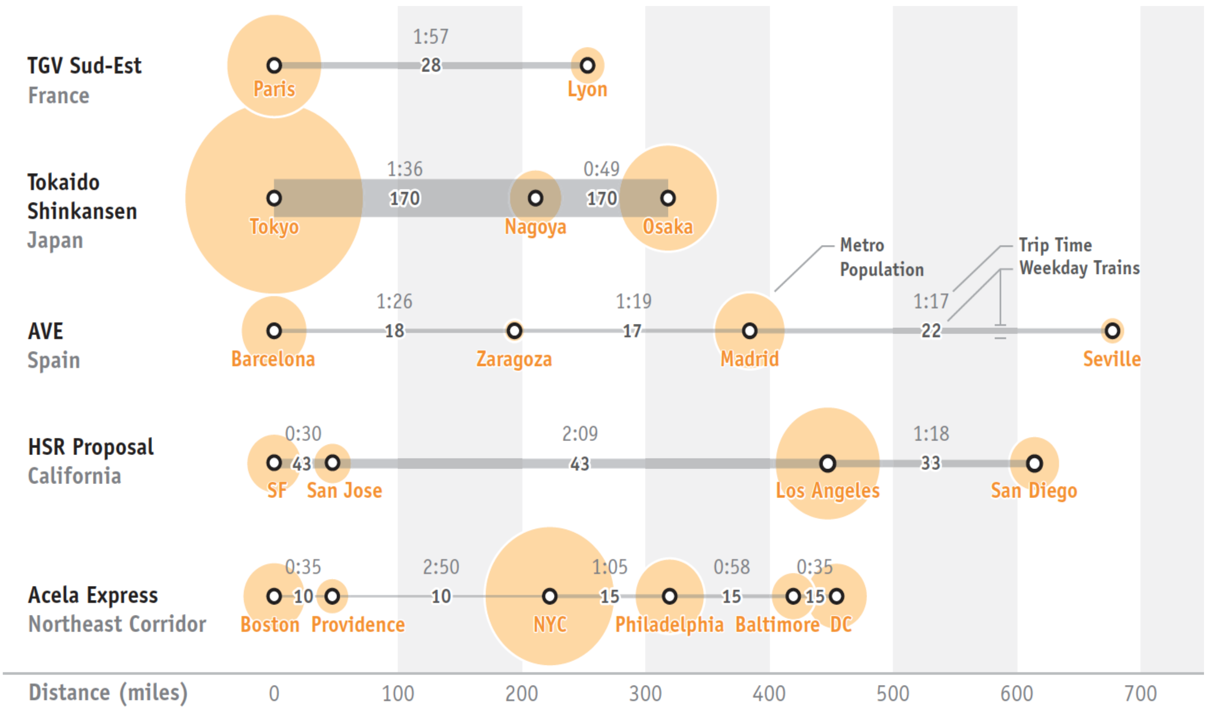


Fig.4- 5 Comparisons of International HSR network (population and distance)

(Retrieved from [13])

(e) The important social or political factors or controversies related to the system

From the political viewpoint, the Texas HSR will be constructed inside only one state, which might make political conflict relatively smaller than in other regional HSR projects [51]. Also, there is no direct conventional passenger rail service between these two cities, which makes political conflict smaller. However, the largest challenge the project faces is that some municipalities, such as Grimes County, and some of the landowners living along the planned route are opposed to the construction. Whether the project goes smoothly or not is up to the legitimacy for TCP to make use of the act of the Eminent Domain, which is defined as the right to condemn private property for the use of some large infrastructure project such as railroad [44].

(e) The historical development and context of the CLIOS System

The origin of the Texas HSR connecting Houston and Dallas was in 1989, when the Texas HSR Authority (THSRA) was established to invite bids for the HSR franchise. A French consortium, called Texas TGV, applied for this privately financed franchise with an ambitious ridership estimate, and Texas TGV was selected as the best primary contractor in 1991. However, four years later, this project was stopped mainly due to difficulties of gathering the huge investment funding. This financial failure was scrutinized in a technical report published in 2004 [52]. The authors calculated the capital cost of the 250-mile HSR corridor, and they estimated the required ridership that would have enabled the consortium to earn sufficient rate of return for the investors. There was no way other than attracting considerably high ridership and keeping the fare relatively high to make the project financially successful. The report added, "[P]opulation growth, short boarding times, and the favorable location of train stations could significantly grow the customer base." [52] The other reason for failure is that Southwest Airlines fiercely opposed the project by "filing a temporary restraining order and a temporary injunction against THSRA." [52] In 1992, the Texas TGV claimed that the legal action by Southwest made the project more difficult to achieve without any delays. Finally, this fierce opposition including Southwest's lobbying to the government officials led to the early termination of the project in 1994. "[T]o avoid the pitfalls of the earlier project, namely inadequate financing and intense opposition from" [53] other industries is necessary to make any HSR project successful in Texas.

Opportunities, Issues, and Challenges

Based on the discussion in the Characteristics Checklists and in Chapter 3, the opportunities, issues and challenges for the Texas HSR are found as follows:

・Estimation shows there will be increasing travel demand between the two cities, and this demand could not be accommodated only by existing air travel and highway [24].

・Congestion of the highway between Dallas and Houston (I-45) is the serious problem for economic growth of these regions, and congestion is predicted to get worse in the near future. HSR could be the solution to provide reliable transportation mode for the people in both cities.

・The simple, single link system of the 240 miles corridor is suitable for HSR implementation. The predicted on-board time (less than 90 min) is competitive with other modes (highway and flight)

・Unlike some other large cities in the US, Houston has underdeveloped mass transit systems, and has sprawling city structure with less population density [51]. On the other hand, in Dallas, the mass transit system is well developed.

・Procurement of vast resources for construction costs is one of the most important challenges. TCP is trying to collect "Texas-based investment" [38], but this process may be a big challenge for TCP before starting the HSR construction.

・There is fierce opposition from landowners and inhabitants of the land along the ROW. In terms of using the Eminent Domain to purchase the required land, the question is "Can the private entity condemn land for 'public good'?" There is no opposition from potential competitors so far. (Southwest Airline or other aviation industry, inter-city bus-operating company etc.)

Preliminary System Goals

During the environmental review of the National Environmental Policy Act (NEPA) process, the purpose of the project was articulated as to "construct and operate reliable, safe and economically viable passenger high-speed rail service between Dallas and Houston" in order to "address mobility- and congestion-related issues" in the current highway corridor [54].

From the information above, we set the preliminary system goals of the HSR project as follows:

・To take advantage of high market potential in Dallas and Houston

・To secure profitability from the operating revenue

・To provide reliable and efficient transportation between the two cities

・To implement the safest and most advanced technology of Japanese HSR

These preliminary goals could be refined if needed before beginning the second stage of the CLIOS process. During this step, several insights gained from the system representation stage are reflected to figure out the refined goals, "what the desired future state of the system should be" when facing several realities [4].

4.2.2 How to Structure the CLIOS System: System Representation Stage

To depict the system diagram, three types of simple shapes connected by several types of arrows are used in the CLIOS Process. Fig. 4-6 shows the components which are used for a specific purpose in the Physical Domain. Following descriptions are according to the explanations in the User's Guide [4].

1. Regular Component (depicted as a circle)

This is the normally used component to depict the elements in the Physical Domain. In some cases, a regular component can represent a physical object (such as "Infrastructure," "Vehicles"), plain idea (such as "Capacity", "Congestion") or more complex concept (such as "Connectivity," "Economic Growth").

2. Policy Lever (depicted as a rectangle)

This component represents what is directly influenced by the stakeholders in the Institutional Sphere (some political institutions, for example) who mainly make their own decision based on their interests. Interactions between each component in the Physical Domain and each actor in the Institutional Sphere are mainly realized by these policy levers.

3. Common Drivers (depicted as a diamond)

This component represents some kind of Regular Component or Policy Lever that are shared through multiple subsystems of the Physical Domain. From that standpoint, this component has several effects on the CLIOS system in a complicated manner.

When considering the system, it is important to set the clear boundary, separate the internal and external factor, and define the problem in a proper manner. To distinguish the inside and outside of the boundary of the CLIOS system, External Factor is depicted as a shaded circle, rectangle or diamond. Internal factors, on the other hand, are depicted as non-shaded diagrams.

By connecting each component with "links" which are shown in Fig. 4-7 we can represent the magnitude of influence and its direction between each component and each actor. To describe the links, we use three types of links characterized as follows:

1) Class 1: links between the components in the subsystem
2) Class 2: links between the components and the actors in the institutional sphere
3) Class 3: links between the actors in the institutional sphere (Retrieved from [4])

The Class 1 links are within the same subsystems of the Physical Domain, which could be analyzed quantifiably through some engineering or econometrical methods. The Class 2 links can be analyzed mainly through qualitative methods because these links represent the interactions and relationships between actors and components inside one of the subsystems in Physical Domain. The Class 3 links express the influence from one of the actors to one or more of the other actors within Institutional Sphere. The actors could be individual stakeholders, private organizations or political agencies, so that it is complicated to clarify the interactions of those actors.

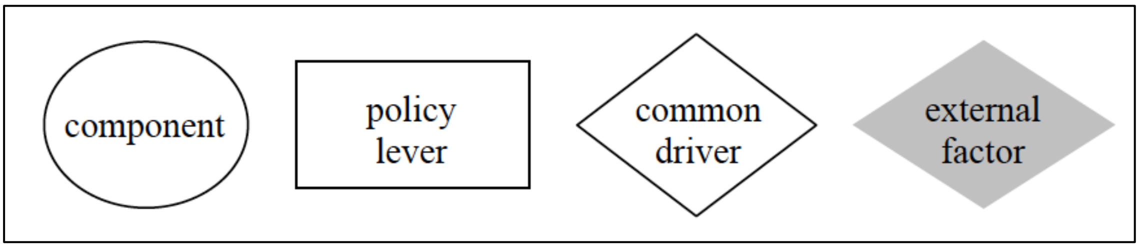


Fig.4- 6 Proposed Shapes of each type of component in diagrams of Physical Domain

(Retrieved from [4])

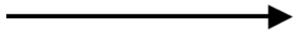
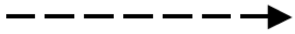
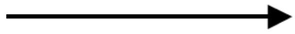
LINK	SHAPE
Class 1 (link between *components* of physical subsystems) Class 3 (link between *actors* on the institutional sphere)	
Class 2 (links "projecting" interactions between the institutional sphere and the physical domain)	
Weak	
Average	
Strong	
Bi-directional	

Fig.4- 7 The type of "links" in the CLIOS representation

(Retrieved from [4])

4.2.3 Five Subsystems in the Physical Domain and Those Components

To structure the physical characteristics of the Texas HSR system, the Physical Domain will be divided into five subsystems, which are generally applicable to any HSR system [55]. The argument that these subsystems and components are not sufficient or lack some information could occur, because the system representations are somewhat arbitrary and subjective. However, to simplify the model and find "new insights and unanticipated relationships," it is useful to pick up only strong and clear links between components based on the mental model of the CLIOS users, as said by Sussman et al. [4].

The five subsystems generally used to analyze HSR system are as follows;

1. Transportation subsystem

This subsystem represents how the users of the specific transportation characterize the system and how the system is influenced by its surrounding environment.

2. Energy / environmental subsystem

This subsystem shows how the external and internal environment, such as environmental regulations or energy policy of the public sectors, affects the transportation system and the other components.

3. Land use subsystem

This subsystem shows how the land use policies or regulation posed by the public sectors will influence the transportation system and the other components.

4. Economic activity subsystem

This subsystem shows how the economic activity will affect the transportation system and the other components. This economic activity includes a wide range of meanings such as labor, investment and supply and demand for any goods or services.

5. Multi-modal transportation subsystem

This subsystem shows how transportation users choose their preferences on their mode choice by considering various factors, such as frequency or connectivity.

In this thesis, two representation diagrams will be shown for each of five subsystems; one representing general transportation system and the other specifically modified for the Texas HSR project. By comparing two diagrams of each subsystem, it is possible to clearly confirm the differences between the Texas HSR project and the other general HSR projects. For each subsystem, we also provide simple explanation of the relationship of these components, whose descriptions are based on the former analyses of Northeast Corridor in the US [55]. Each subsystem includes thirteen to seventeen components and the causal links between them. For the general HSR representation, the total number of components is 52, including 31 regular components (six of which are external factors), 10 policy levers and 11 common drivers. We add one common driver and one policy lever to specifically characterize the Texas HSR project: Car Ownership and Land Acquisition. All of thesecomponents are shown in Table 4-3, and their causal relationships are shown in Table 4-4.

Table 4- 3 Descriptions of the Components in the Physical Domain

Type	#	Name of Components	Description
Common Drivers	1	Transportation Demand	Combination of O-D patterns and volumes. It includes both the aggregate and disaggregate demand
	2	Energy Output	Mode, amount availability, reliability and cost
	3	Transportation Service	Transportation operations, including frequency, reliability and quality of service
	4	Modal Split	Share of the transportation demand per mode
	5	Air Emissions	Both greenhouse gases and Nox
	6	Trip Attributes	Includes in-vehicle travel time, waiting time at stops, transfer time, walking time, safety, security, reliability and comfort
	7	Network Usage	Usage volumes per mode. Subject to capacity constraints
	8	Transport Revenues	Revenues obtained from providing transportation services
	9	Land Usage	Specifies location, quantity and type of land
	10	Economic Activity	Vector of GDP, GDP per capita and income distribution
	11	Private Investment	Private investment in all sectors of the economy including transportation
	★12	Car Ownership	High car ownership rate affecting mode choice of the passengers
Regular Components	13	Transportation Infrastructure	Infrastructure, signals, ROW, stations, etc.
	14	Congestion	All kinds of congestion (road, rail, air)
	15	Fuel Prices	Includes gasoline, diesel and jet fuel prices
	16	Other Environmental Impacts	Water pollution, nuclear waste, habitat destruction, and additional environmental impacts not captured in the other components
	17	Energy Generation Infrastructure	The physical infrastructure required to generate electricity
	18	Energy Transmission Infrastructure	The physical infrastructure required to distribute electricity
	19	Human Health and Environmental Sustainability	Considers human health effects and long-term environmental sustainability
	20	Land Demand	This component specifies the quantity, type and preferred location of land desired
	21	Land Costs	Results from the interactions between land supply and demand
	22	Land Supply	Quantity and type of land available at a given location
	23	Demographics	Statistical characteristics of population
	24	Physical Characteristics of Land	Physical and artificial characteristics of land
	25	Land Accessibility	Refers to the ability of goods, services, energy, etc. to reach the land
	26	Firm's Costs and Capacity	The firm's production and cost functions
	27	Foreign Investment	Similar to private investment, but specifically considering foreign sources
	28	Demand for Goods and Services	The quantity of goods and services that primarily individuals demand
	29	Labor	Quantity, type and cost of labor. Saturation (employment) level
	30	Capital	Includes type, quantity and cost of capital
	31	Transportation	The physical infrastructure between nodes for all modes
	32	Transportation Nodes	Physical terminal/station infrastructure for all modes
	33	Transportation Vehicles	Refers to vehicles operated by all modes of transportation(e.g. cars, buses)
	34	Transportation Frequency	The service plan of the operators
	35	Transportation Capacity	The number of people or amount of goods that can be transported per mode per unit of time
	36	Transportation Coverage	The number of people or the amount of goods that is in close proximity to a mode
	37	Transportation Connectivity	The concept of how well the modes are connected

Type	#	Name of Components	Description
Policy Levers	38	Transport Funding and Investment	Federal and state investment
	39	Transport Operations Subsidy	How much the government chooses to subsidize transportation operations
	40	Fuel Tax	Excise fuel tax
	41	Energy Investment	Monetary investment in energy
	42	Energy Policies	Environmental and technical policies
	43	Environmental Policies	US EPA's regulations
	44	Land Use Policies	Primarily state and local policies
	45	Federal and State Fiscal Policies	Allocation of expenditures
	46	Taxes	Includes business and personal taxes
	47	Inter-Modal Transportation Integration Policies	How well transportation agencies/operators interact between modes and how well infrastructure is able to serve multiple modes
	★48	Land Acquisition	Compulsory purchase of land by the Eminent Domain Act
External Factors	49	Weather	Weather and environmental conditions. It is also a common driver
	50	Global Fuel Prices	The market price of petroleum products
	51	Energy Sources	Wind, solar, water, nuclear, coal or gas availability
	52	Natural Characteristics of Land	Includes slope, type of soils, climate conditions, etc.
	53	Foreign Economies	Foreign economic factors largely outside of government control
	54	Macroeconomic Factors	Economic factors largely outside of government control

*The components shown with a star mark (★) are specific components for Texas HSR project

(Partially Retrieved from [4])

Table 4- 4 Components checklist for each Subsystem

CLIOS Physical Domain Subsystems Table		Subsystem: transportation	Subsystem: energy/ environmental	Subsystem: land use	Subsystem: economic activity	Subsystem: multi-modal transporta	linkage: affected by	linkage: affect to	linkage: Physical Domain
Component circle	Congestion	○					Network Usage	Air Emmisions, Trip Attributes	Transportation
	Infrastructure	○					Public Trp. Funding & Investment, Private Invetsment, Transp. Revenue	Transportation Service	Transportation
	Fuel price	○					Fuel Tax, Global Fuel Prices	Trip Attributes	Transportation
	Energy transmission infrastructure		○				En. Investment, En. Policies, Land Usage, Econ. Activity	Land Usage, Energy Output	En./Environmental
	Energy generation infrastructure		○				En. Sources, En. Investment, En. Policies, En. Output, Econ. Activity	Air Emmisions, Env. Impact, En.Output	En./Environmental
	Other environmental impact		○				Env. Policies, En. Generation Infrastructure, Land usage	Human Health&Env. Sustainability	En./Environmental
	Human health&envi. l sustainability		○				Air Emmisions, Other Env. Impact, Weather	Ecinomic Activity	En./Environmental
	Land demand			○			Economic activity, Demographics	Land Cost, Land Usage	Land Use
	Land supply			○			Env. Policies, Land Use Policies, Physical Characteristics of Land, Land Accissibility	Land Cost, Land Usage	Land Use
	Land Cost			○			Land Demand, Land Supply	Land Usage	Land Use
	Land accessibility			○			Land Usage, Trp. Service, Energy Output	Land Supply	Land Use
	Physical characteristics of land			○			Natural Characteristics of Land, Transportation Demand	Land Supply	Land Use
	Demographics			○				Land Demand	Land Use
	Firm's cost and capacity				○		Taxes, Capital, Trp, Service, Energy Output, Land Usage	Land Usage, Economic Activity	Economic
	Capital				○		Foreign Investment, Private Investment, Federal/State Fiscal Policies	Firm's Cost & Capacity	Economic
	Labor				○		Taxes	Demand for Goods & Services	Economic
	Demand for goods and services				○		Labor, Land Usage	Economic Activity, Land Usage	Economic
	Foreign Investment				○		Foreign Economies, Taxes	Capital	Economic
	Linkages					○	Private Investment, Public Trp. Funding&Investment	Capacity, Coverage	Multi-Modal Transportation
	Nodes					○	Private Investment, Public Trp. Funding&Investment	Capacity, Coverage	Multi-Modal Transportation
	Vehicles					○	Private Investment, Public Trp. Funding&Investment	Capacity	Multi-Modal Transportation
	Frequency					○	Private Investment, Public Trp. Funding&Investment	Capacity	Multi-Modal Transportation
	Capacity					○	Vehicles, Frequency, Nodes, Linkages, Network Usage	Trip Attributes	Multi-Modal Transportation
	Coverage					○	Nodes, Linkages, Network Usage	Trip Attributes	Multi-Modal Transportation
	Connectivity					○	Intermodal Integration Policies	Trip Attributes	Multi-Modal Transportation
Component (External)	Global fuel price	○						Fuel Price	Transportation
	Energy sources		○					Energy Generation Infrastructure	En./Environmental
	Natural charactersitics of land			○				Physical Characteristics of Land	Land Use
	Foreign Economies				○			Foreign Investment	Economic
	Macroeconomic factors				○			Economic activity	Economic

Transportation subsystem

Fig. 4-8 shows the general transportation subsystem. In this diagram, a broad range of transportation modes is included, so that we can represent general information of the environment relevant to the transportation system. Sussman et al. said that “[S]ome of the components may not be applicable for all transportation modes” [55], but it is useful for understanding the whole picture of the subsystem. Detailed description closely related to the HSR system is included in the Multi-modal Transportation Subsystem, whose information is about transportation infrastructure and multi-modal services.

In this subsystem, Transportation Demand is directly affected by Trip Attributes which are compounds of several utilities such as Fare, Travel Time, Frequency and so on. Modal Split is the result of Transportation Demand, Trip Attributes and Weather. Weather is an external factor and also has a large impact on Trip Attributes of each transportation mode. One of the most important aspects of the transportation system is its profitability, which is directly related to the amount of Transportation Revenue. It is yielded by Network Usage, which is determined by Modal Split and Transportation Demand. The negative impacts of transportation, such as Air Emissions and Congestion, are also related to Network Usage. Of course, Congestion could have a great impact on Trip Attributes from the viewpoint of travel time, safety issues and discomfort of the users. Transportation Revenue, on the other hand, has a large impact on Public Transportation Funding & Investment because part of reinvestment to infrastructure comes from Transport Revenue. Transportation Infrastructure is generally developed and maintained by using Public Funding and Investment, which affects Transportation Service of shared mode (for example, mass transit system or public bus services) directly and through Transportation Infrastructure as well as from Transportation Operation Subsidy. From the viewpoints of energy, Energy Output, which is a common driver with the Energy Subsystem, affects Trip Attributes mainly of public transportation. In addition, Fuel Prices, which are affected by Global Fuel Prices and Fuel Tax also affects Trip Attributes of the flight industry and private car, for example. Finally, Fuel Tax has large impacts on both Public Funding & Investment and Transport Revenue. These causal relationships are depicted as one closed feedback loop in the diagram. Also, several common drivers, such as Transportation Demand and Modal Split, can be found on another or more of other subsystems and sometimes affected by other components.

When we modify this subsystem for the specific purpose of understanding the Texas HSR project, two common drivers, Private Investment and Car Ownership, should be implemented in the subsystem as shown in Fig. 4-9. These components and links are written in red, because the Texas HSR will be financed without any US government funding and Private Investment affects Transportation Infrastructure and Transportation Service directly. Transportation Revenue will also be used for reinvestment of infrastructure and improvement of transportation services; therefore Transportation Revenue is linked with both Transportation Infrastructure and Transportation Service. The high rate of Car Ownership in Texas has a large impact on the Modal Split of this region and Congestion. Even after the implementation of the HSR system, it will be likely remained difficult to persuade people to use other new mode than private car. On the other hand, Public Funding and Investment and Operation Subsidy no longer have impact on the project. As a result, these components and links should be eliminated from the diagram, but for clarification of the differences, we depict these components by faded shapes and letters. By comparing these two diagrams, we can clearly understand the characteristics of the Texas HSR project, which is financially independent of the public sector. This characteristic is more articulated in an explanation of the Multi-modal Transportation Subsystem.

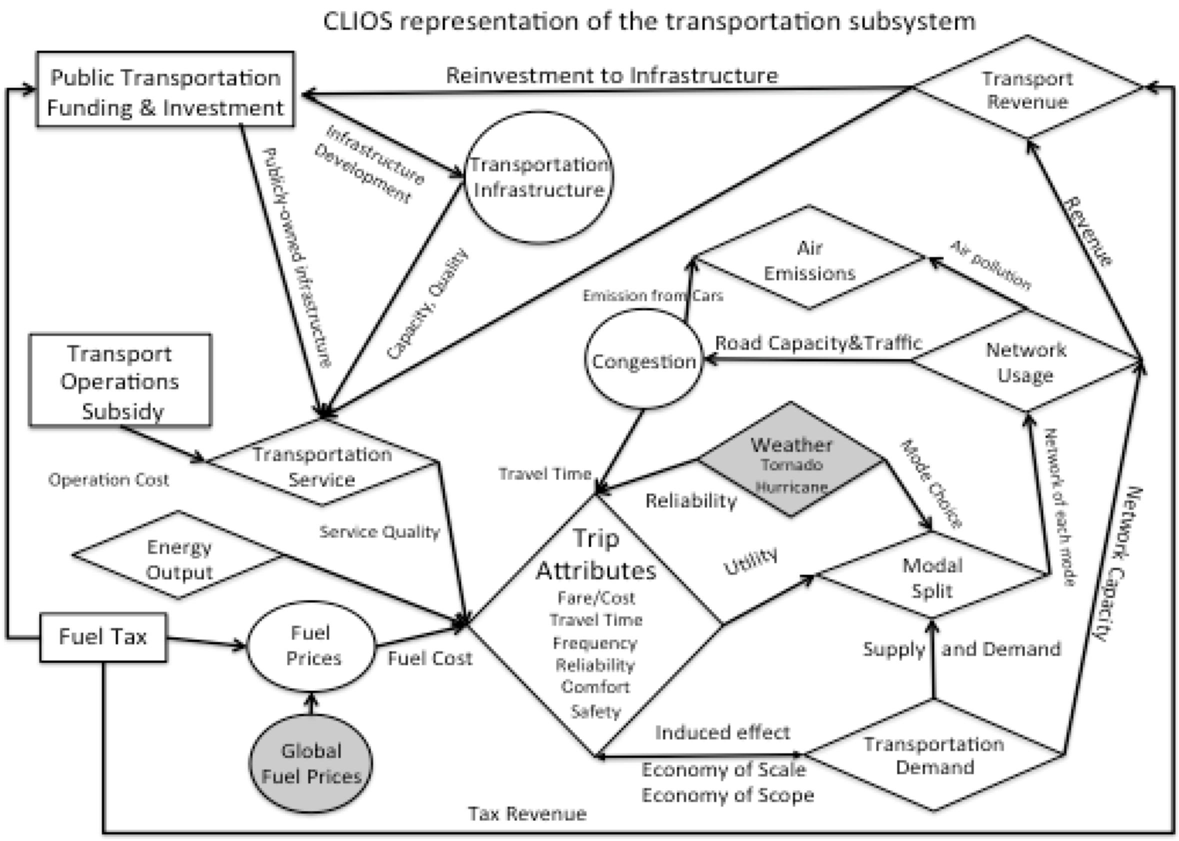


Fig.4- 8 Transportation Subsystem for general system

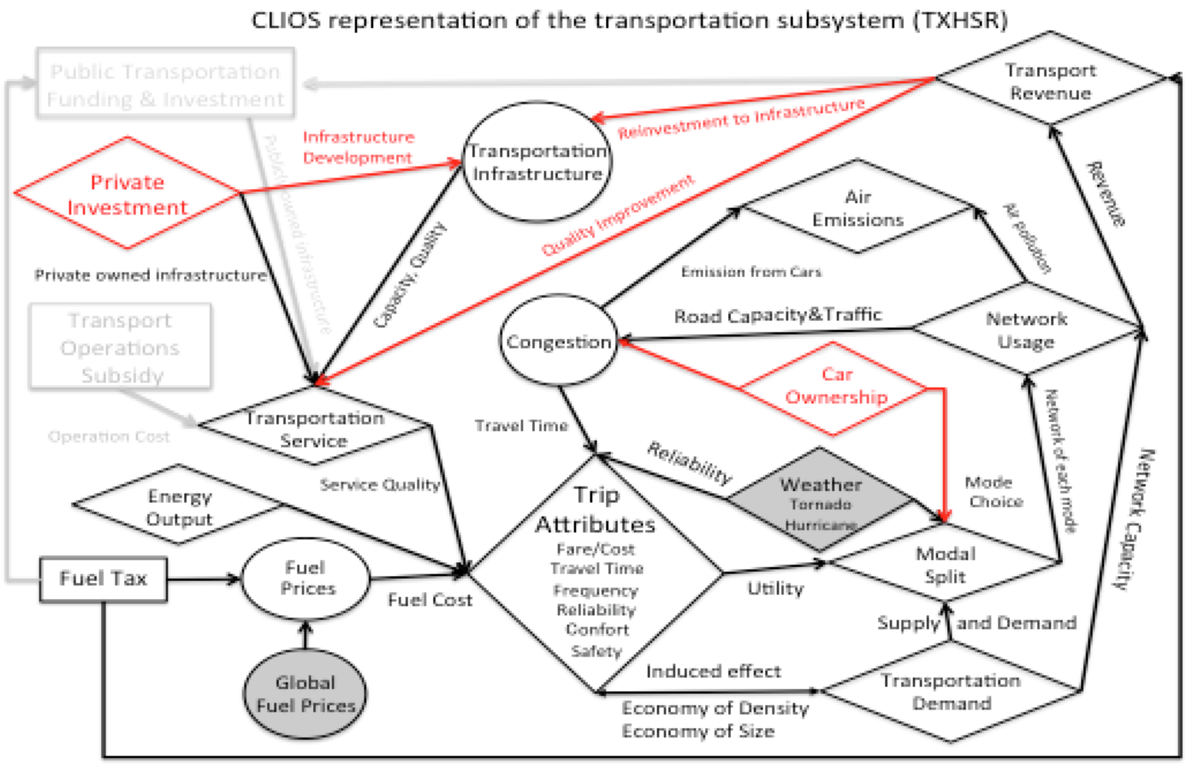


Fig.4- 9 Modified Transportation Subsystem for Texas HSR project

(Partially Retrieved from [4])

Energy / Environmental subsystem

Fig. 4-10 shows the general Energy/environmental subsystem. There are three common drivers that are closely related to the HSR system. Two of those common drivers are Land Usage and Economic Activity, both of which are defined in the other subsystems. The most impactful component in this subsystem is Energy Output, which is defined as “Mode, amount, availability, reliability and cost” of energy in Table 4-3. The condition of Energy Output is mainly determined by Energy Generation Infrastructure and Energy Transmission Infrastructure. These infrastructures are affected by Energy Policy, Energy Investment and Energy Sources available for the community. Another important aspect is that the Energy Transmission Infrastructure is linked with Land Usage bilaterally. This is because “land use is conditioned to the existing energy transmission infrastructure, but, at times, the need for more land with access to electricity induces an extension of the energy transmission infrastructure” [55]. Energy Transmission Infrastructure also drives the Economic Activity by providing efficient and reliable transmission of energy to the destination. Then, not only energy usage but also environmental impacts should be considered seriously in this subsystem. Air Pollution and Other Impacts, including Noise, Vibration and Water pollution caused by the Energy Generation Infrastructure, are the examples of such negative impacts. These negative impacts as well as Weather condition can affect Human Health and Environmental Sustainability. Human Health and Environmental Sustainability, which is directly linked with Economic Activity, is a key factor to realize the sustainable growth of the society and the mitigation of climate change. Another policy lever, Environmental Policies, pose some regulations to reduce Air Emissions and Other Environmental Impacts. Therefore, the energy resources are chosen based on what is the most balanced energy mix in the region.

As shown in Fig. 4-11, the overall structure of the subsystem modified for the Texas HSR project is almost the same except that it includes high Car Ownership having large impact on Air Emissions. From the viewpoint of the HSR operator, it is important to secure reliable transmission network to supply electricity to the electrical system of the HSR. The Texas HSR line is supposed to be constructed on the Utility Corridor, which is along with high voltage power line between Houston and Dallas. HSR operator should take care of the environmental impact by providing sufficient information about noise, vibration and water contamination during its construction and operation. These impacts will be evaluated in the Environmental Impact Assessment according to the National Environmental Policy Act (NEPA).

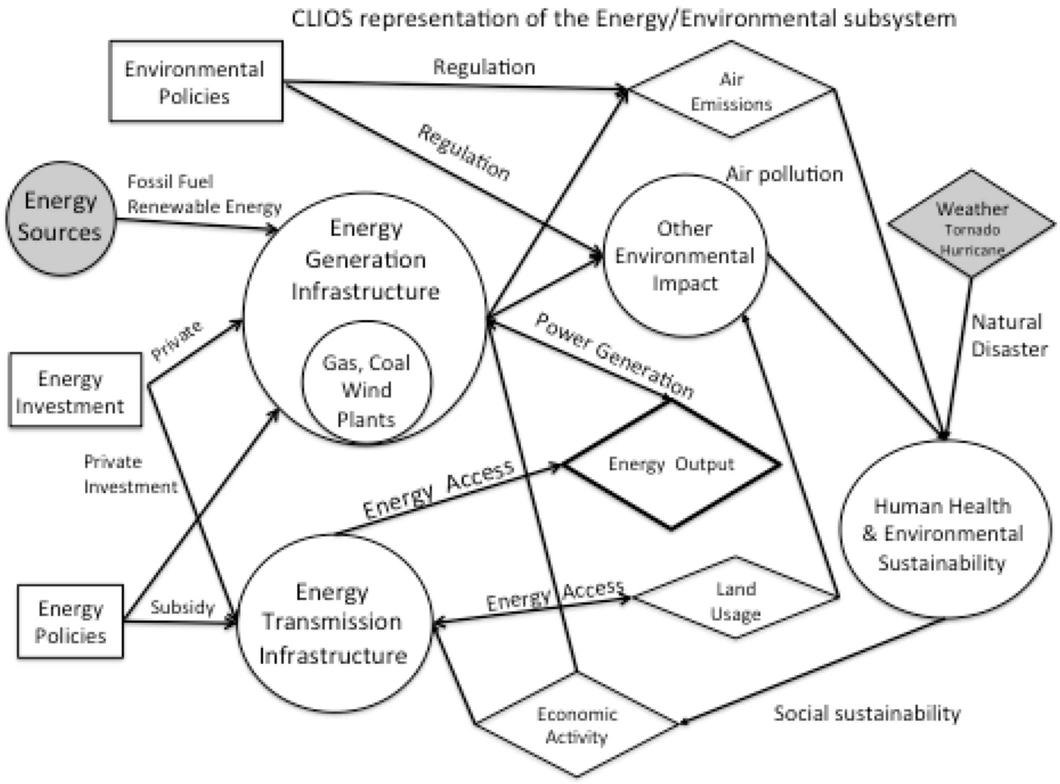


Fig.4- 10 Energy/environmental Subsystem for general system

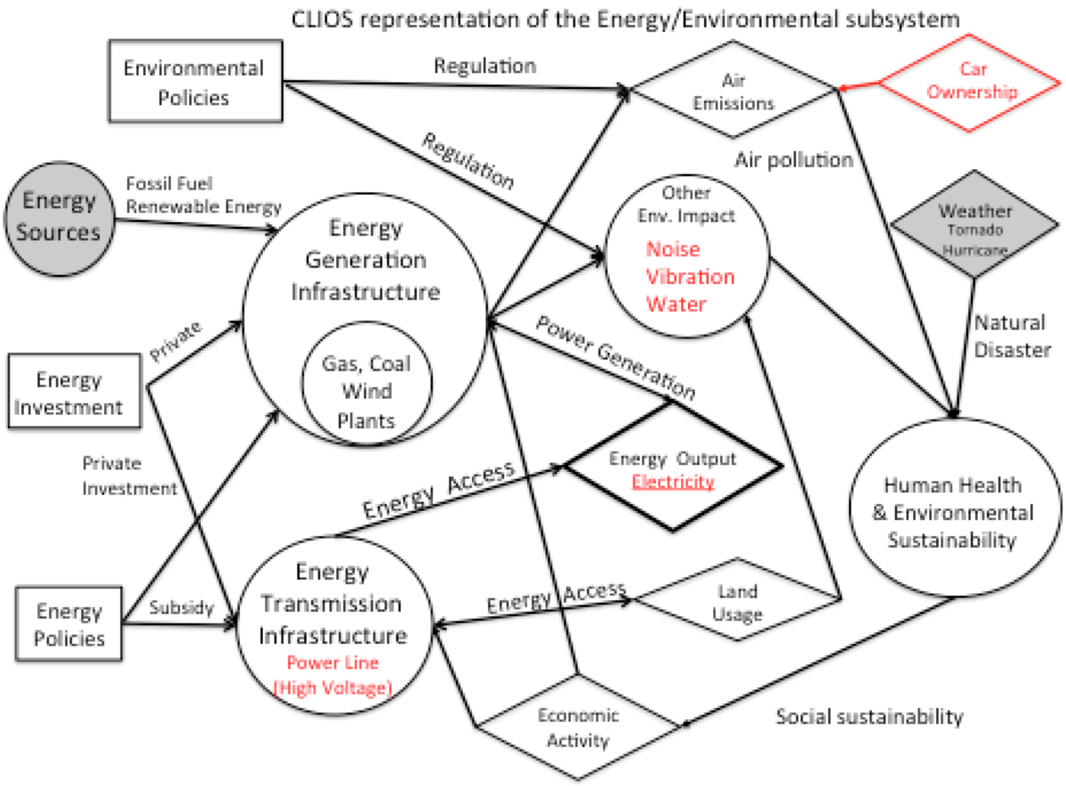


Fig.4- 11 Modified Energy/environmental Subsystem for Texas HSR project

(Partially Retrieved from [4])

Land Use Subsystem

Fig.4-12 shows the general Land Use Subsystem. This subsystem represents the distribution of activities, which can gradually change over a long time period. The first common driver, Land Usage, is an important factor when considering Transportation Demand in the region. This Land Usage is mainly determined by both Land Demand and Land Supply. The Land Usage is also affected by Land Cost, which is determined by the balance of Land Cost and Supply. The Land Demand is affected by two human-related factors, Economic Activity and Demographics. The Land Supply is mainly affected by Physical Characteristics of Land, which is the result of Natural Characteristics of Land and Transportation Demand of the region. The Land Accessibility, which is an extent of transferability of goods, services, energy and people, is another factor affecting the Land Supply. Transportation Service and Energy Output, as well as Land Usage itself, affect Land Accessibility. From the viewpoint of the public sector, it can have an impact on the Land Supply through Environmental Policies and Land Use Policies, both of which could be some type of regulation.

Fig.4-13 shows a modified version of Land Use Subsystem of the Texas HSR project. First of all, the high Car Ownership rate can strongly affect the Land Usage and Land Accessibility of the region. The city of Houston has a typical sprawling structure into the suburban areas [56]. People rely heavily on the use of private car, and so it seems difficult to change the people's tendency to use public transportation when they access the HSR station.

The other modification is to add the policy lever of Land Acquisition through Eminent Domain, which affects the Land Supply for the HSR operator. Because this project is fully privately funded, the project needs a good reason to justify the use of Eminent Domain; by saying the project serves the "public good." The HSR operator has tried to make a good public relationship to persuade people in Texas [38]. One of the key factors to success is to purchase the required land from landowners by negotiation. If landowners will not agree, the rail project must be admitted by the Texas government as for the "public good" to apply the Eminent Domain.

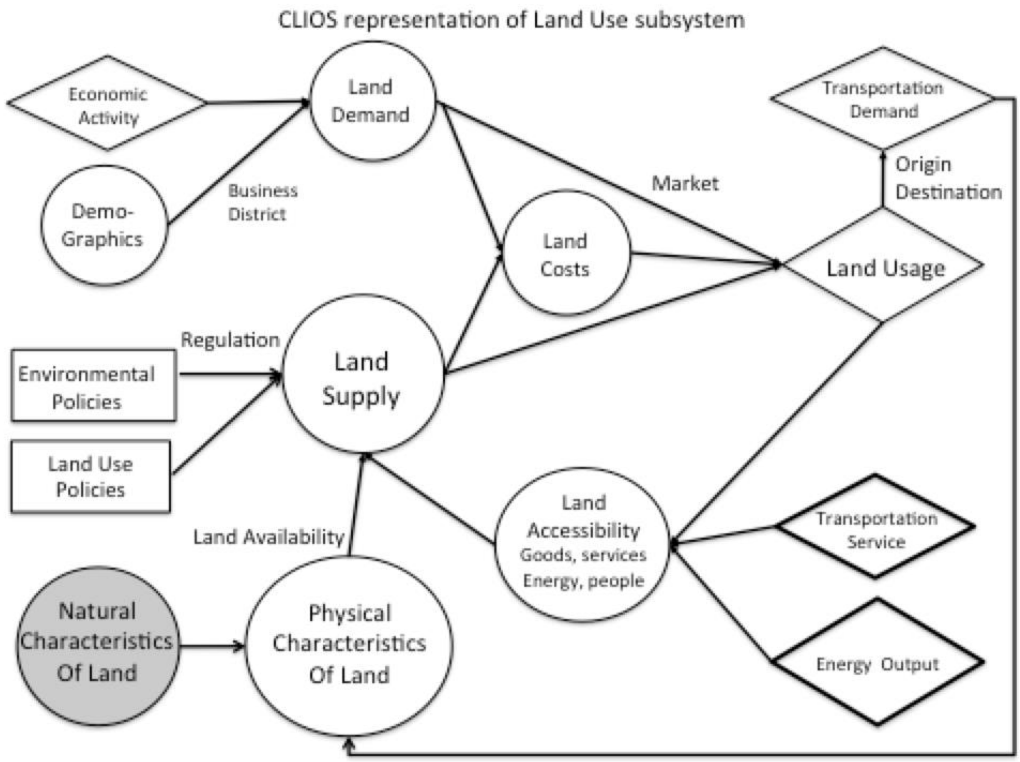


Fig.4- 12 Land Use Subsystem of general system

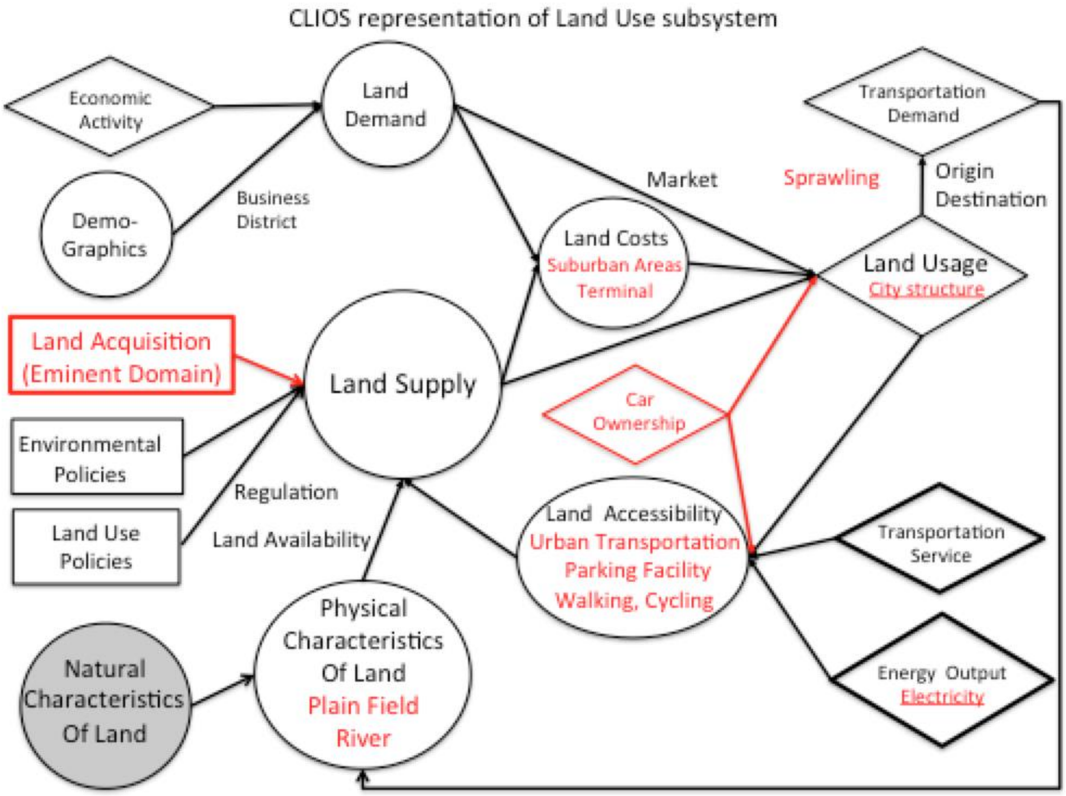


Fig.4- 13 Modified Land Use Subsystem for Texas HSR project

(Partially Retrieved from [4])

Economic Subsystem

Fig. 4-14 shows the general Economic Subsystem. This subsystem represents overall economic activity in the region, and the Transportation Demand depends largely on the sustainable growth of Economic Activity, one of the common drivers in this subsystem. The Economic Demand is determined by the balance of supply (Firm's Cost and Capacity, which represents the company's price competitiveness and production capacity) and demand (Demand for Goods and Services, which represents the need for actual goods or any services by Labor). Firm's Cost and Capacity is the function of Capital, Transportation Service, Energy Output, Taxes and Labor, all of which are the determinants of cost and availability of inputs for goods and service production. The Transportation Service, the Energy Output and the Land Use are common drivers so that they are bilaterally connected with Firm's Costs and Capacity through other subsystems. The relationships between these common drivers are complicated, and they have multiple feedback effects with each other. The Labor is defined as "Quantity, type and cost of labor, Saturation (employment) level" in Table 4-3, therefore Labor is a representation of employment and wages so that it can be the base of demand of goods and services. The Demand is distributed related to Land Usage, and Land Usage can be changed gradually due to the effect of the Demand distribution, so the link between these two components is a type of bilateral causal relationship. The Capital can be supplied from Federal or State Fiscal Policies in the form of subsidies, or from Foreign Investment that is affected by Foreign Economies. The component of Foreign Economies is one of the two external factors in this subsystem as well as Macro Economic Factors. The other source of Capital is Private Investment that can be attracted by Economic Activity in the region.

From the modified subsystem in Fig. 4-15, we can understand the new pattern of Capital that is required to construct and operate the new HSR system. Subsidies from Federal or State Policies cannot link with the Capital because the Texas project is based mainly on private funding and no US government funding. On the other hand, the Capital can be supplied from the Foreign Investment fund backed by Japanese government [42]. The HSR operator has now tried to procure a vast amount of money only from the private sectors, so that the Private Investment is the key factor to success in the first step of the project. In this subsystem, Labor affects Car Ownership because the ownership rate increases as the wage level increases. This additional common driver has impact on Firm's Cost and Capacity through Transportation Service, which is the common driver of the Transportation subsystem and Economic subsystem.

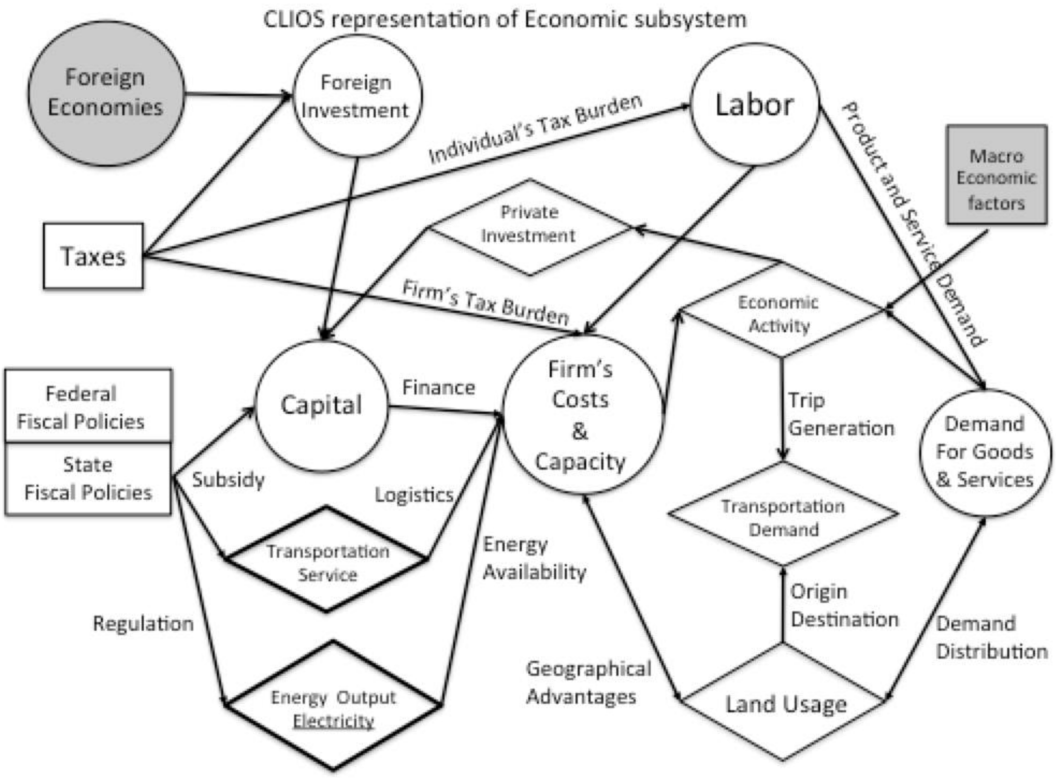


Fig.4- 14 Economic Subsystem of general system

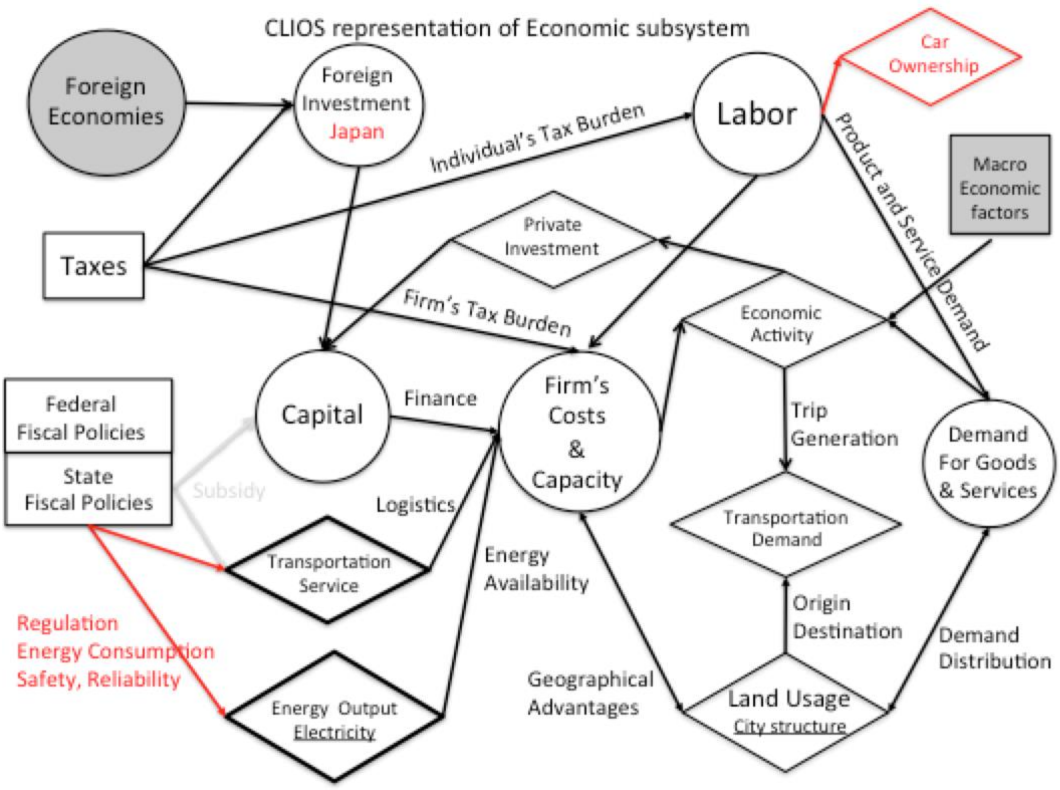


Fig.4- 15 Modified Economic Subsystem for Texas HSR project

(Partially Retrieved from [4])

Multimodal Transportation Subsystem

Fig.4-16 shows the general Multimodal Transportation Subsystem. This subsystem is introduced to articulate various aspects in Transportation Infrastructure and Transportation Service. First, four regular components, Vehicles, Frequency, Nodes and Linkages, are considered to be essential elements of any transportation mode in the public and private sectors. Nodes, which are transportation facilities such as airports, stations, parking lots and bus stops, and Linkages, the example of which are highways, ROW of rail, and track etc., constitute the overall transportation networks. On these networks, some type of Vehicles is used at a certain Frequency. Frequency can represent schedule of train, bus and other shared transportation, or "the pattern of linkages that [a vehicle] follows." [55] Capacity is a function of all four of these components. Nodes and Linkages determine Coverage, which represents the number of people or volume of goods and services that can be transported from origin to destination in the area. Coverage and Capacity basically determine the Trip Attributes, which is one of the important common drivers shared with the Transportation Subsystem. The other factor that affects the Trip Attributes is Connectivity between each mode. The Connectivity is created efficiently by proper Intermodal Integration Policies. As we mentioned in the explanation of the Transportation Subsystem, the Trip Attributes determine the Modal Split providing some utility, and the Network Usage is importantly affected by the Modal Split. The Network Usage can vary the Capacity and Coverage of the transportation system in the region, and so there is a feedback loop among the Trip Attributes, Modal Split and Network Usage. As a result of the Network Usage, Transport Revenue is yielded and it is used for operation and reinvestment in infrastructure. Therefore, Private Investment and Public Funding and Investment are strongly affected by Transport Revenue. Both types of Investment can be used for the improvement of Nodes, Linkages, Frequency and Vehicles. Therefore, those four components can change the Capacity and Coverage of the transportation system. This is a key to high quality transportation service.

Considering the situation of the Texas HSR project, Public Funding and Investment is deleted from the subsystem as shown in Fig 4-17. Only Private Investment can be used for the improvement of four components, Nodes, Linkages, Frequency and Vehicles. All of the Transport Revenue yielded from the HSR operation can be a part of Private Investment to be spent for securing profitability and reinvestment. The other specific factor that affects Connectivity is high Car Ownership rate in Texas. People tend to use a private car to access other transportation Nodes, such as HSR terminus stations. Whether we should provide good quality of public transportation for people to access the HSR stations will be discussed in Chapter 6.

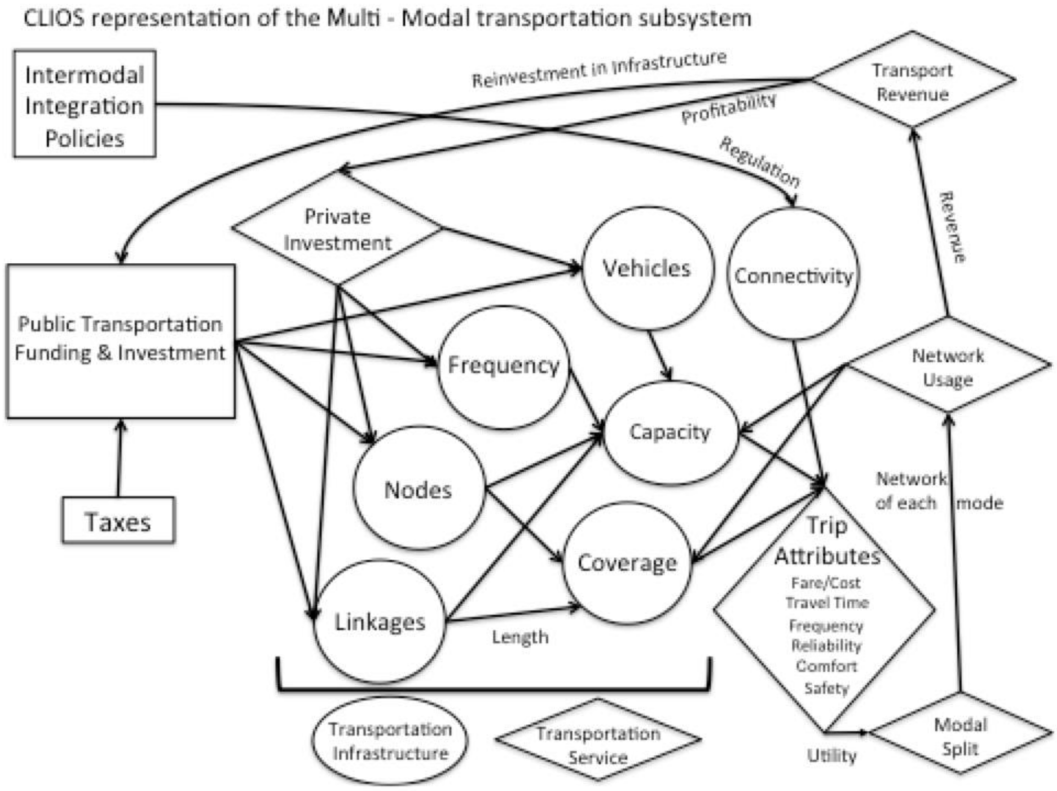


Fig.4- 16 Multi-modal Transportation Subsystem of general system

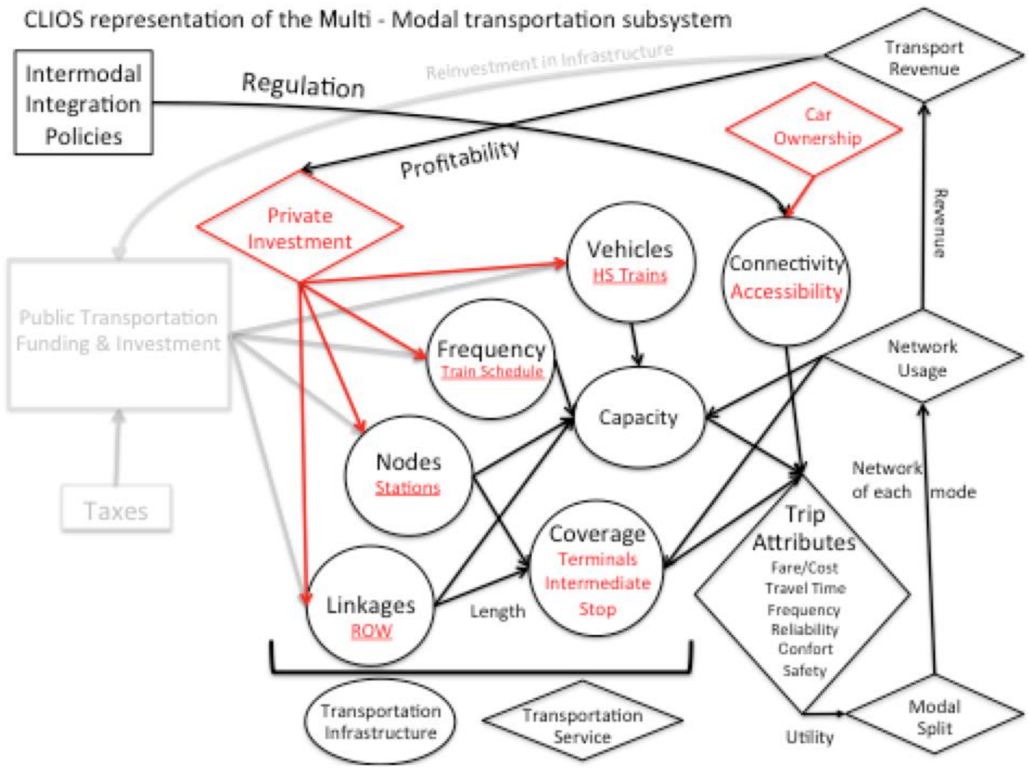


Fig.4- 17 Modified Multi-modal Transportation Subsystem for the Texas HSR project

(Partially Retrieved from [4])

4.2.4 Institutional Sphere

The next step for the CLIOS representation stage is to describe every "actor" in the Institutional Sphere. This process is to identify the actors' characteristics, their interests in the Physical Domain, and the relationship between each actor in the Institutional Sphere. As in the usual case of analyzing the HSR project, the actors should be classified into three categories [4]:
(1) Government (2) Private sector, and (3) Transportation users.

These categories are shown in Table 4-5.

Table 4- 5 Three Categories of the Actors in the Institutional Sphere

The Actors in the Institutional Sphere		
Government	**Private Sector**	**Transportation Users**
・Federal Government Congress, USEPA, USDOE USDOC USDOT (FRA, FTA, FHWA, FAA) ・State Government Texas DOT ・Local Government Municipal (City, County) MPOs, Urban Public Transportation Operators(DART, T, METRO) ・Other Government Japanese government JOIN	・Promoter TCP, CJR Consortiums of construction/ consultation companies ・Stakeholders Private Investors Land Owners Political Activists (Think tanks, Local committee) Aviation industry Airport Intercity bus operator	・Intercity business passengers ・Intercity private passengers

(1) Government

Federal Government

・The Congress

The Congress, consisting of the Senate and House of Representatives, is the Legislative branch of the Federal political systems. Because, in general, any funding of the Federal budget has to be approved by Congress, publicly funded HSR projects are strongly affected by the political parties. For example, the Obama Administration passed the American Recovery and Reinvestment Act in 2009 to promote the implementation of the HSR networks all over the US. But after the Republican Party regained their majority in House of Representatives in 2010, it became more difficult to provide any federal funding for HSR construction. In the case of the Texas HSR project, however, it needs no federal funding so that Congress does not have a direct financial influence on the project as it does on the other HSR projects. However, under the U.S. Constitution, Congress has the power to provide statutory mandate over Administrative Agencies described below. Thus, Congress is still an important actor in the Institutional Sphere.

・United States Environmental Protection Agency (USEPA)

The USEPA is one of the executive agencies in the federal government, which has the authority to implement regulations and the national standards to reduce environment and safety concerns, based on laws passed by the US Congress. The main mission of the USEPA is to ensure "all Americans are protected from significant risks to human health and the environment where they live, learn and work" [57]. With regard to the HSR project, the USEPA has a concern with the environmental impacts coming from the huge infrastructure, such as air pollution, water contamination, and land use problems. Before the start of construction, the private entity has to conduct an Environmental Impact Statement (EIS) mandated by the National Environmental Policy Act (NEPA), which establishes the national standard process for maintaining healthy environment. This process is conducted by the project promoter and Federal Railroad Agency (FRA), and will be administered by the USEPA. The environmental issues should be seriously treated especially when considering the place of the terminus stations in Dallas and Houston areas.

・United States Department of Energy (USDOE)

The USDOE is one of the executive agencies in the federal government, whose official mission is to "ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions." [58] Because HSR technology consumes a considerable amount of electricity, it is necessary for the operator to secure the reliable source of energy during both construction and operation phases. The USDOE's decision could have an impact on the project in terms of electricity cost, which depends on what energy sources they prioritize for generating the electric power. The potential competitors of HSR are likely to use energy sources (mainly diesel or gasoline) different from HSR, so it is important to estimate the tradeoffs of increasing HSR ridership in exchange for car and flight travel demand from the viewpoint of energy consumption [55]. In general, the energy consumption level of HSR is highly competitive with other travel modes if its average load factor is sufficiently high [59].

・United States Department of Commerce (USDOC)

The USDOC is one of the executive agencies in the federal government. The USDOC's mission focuses on "job creation, economic growth, sustainable development and improved standards of living for all Americans."[60] The areas of USDOC's responsibility are wide ranging from technology development, export and import of hazardous goods to protection of intellectual property and so on. The potential mission of the HSR project, which can enhance the inter-regional mobility and, therefore stimulate the economic growth of connected regions, is consistent with the mission of the USDOC. Especially, the USDOC has a responsibility in terms of the trade of goods and services, so that the HSR technology can help it to realize its goal of enhancing business relationships between people who live in the two metropolitan areas in Texas.

・United States Department of Transportation (USDOT)

The USDOT is one of the executive agencies in the federal government, whose mission is to "[s]erve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future."[61] The USDOT's activities include making regulations, conducting research, organizing and reporting statistics and taking initiative to make future plans in the area of all transportation modes. Therefore, the USDOT is generally the most influential governmental agency on the Texas HSR project. The USDOT has several operating administrations, each of which has its own jurisdiction. They include the Federal Railroad Administration (FRA), the Federal Transit Administration (FTA), the Federal Highway Administration (FHWA), the Federal Aviation Administration (FAA), and the other transportation-related organizations. The USDOT annually has budget allocation to fund the important infrastructure reinvestment projects, but this is not likely to affect the privately funded Texas HSR project.

・Federal Railroad Administration (FRA)

Although none of the annual budget from the FRA is likely to be invested into the Texas project, the FRA is the most influential administration in the government because it has the authority to make regulations, and therefore, has a strong control of the Texas HSR project. FRA's Passenger Rail Division has now tried to set the safety standards, which has a direct impact on cost estimation, for the project. The Passenger Rail Division has a mission to "[p]rovide technical expertise and direction in the execution and administration of Passenger Rail Safety Programs to ensure maximum safety in" not only conventional rail but also in high speed rail projects [35]. For the HSR running above 150 mph, it requires new regulations to be implemented. One of the solutions that the Texas HSR project seeks is Rules of Particular Applicability (RPA), which is defined as "Regulations that apply to a specific railroad or a specific type of operation."[35] To use Japanese "Shinkansen" technology, which is totally based on different safety structure from that of the general US railroad systems, the HSR project has to require the FRA to admit RPA before implementing the system. The Rail Safety Advisory Committee (RSAC) is the FRA's advisory committee that is established to assist in rulemaking. It promotes a collaborative rulemaking process by "all concerned stakeholders interested in railroad safety" [35].

・Federal Transit Administration (FTA)

The FTA has a budget to fund for mass transit systems and oversees safety issues and social justice of public transit. It cannot directly affect the Texas HSR project, which is inter-regional, but the accessibility to the HSR stations is secured by a feeder transit system, such as a commuter rail and other types of urban transportation. Accessibility to the stations is one of the key issues for the HSR operator to make the HSR more convenient for passengers and, therefore, more competitive with other modes.

・Federal Highway Administration (FHWA)

The FHWA oversees the entire interstate highway network in the US. In Texas, highway networks are well developed, and people tend to move from one region to another region by their own private car using this large highway network. I-45 runs from Dallas to Galveston passing through Houston, and so its users are considered to be the potential HSR passengers after the commencement of the HSR between the two cities. Due to heavy congestion and a predicted worse situation in the future [62], the FHWA would provide grants to expand the intercity highway networks, and so it could directly affect the ridership of the HSR. Therefore, to estimate the demand for the HSR, it is necessary to consider the impact from the highway expansion planned by the FHWA.

・Federal Aviation Administration (FAA)

The FAA oversees all of the flight-related industries including domestic and international airline companies, aircraft manufacturers and airports in the US. The direct impact from the FAA on the Texas HSR project is very limited, but the aviation industry is one of the potential competitors after the commencement of HSR operation. In the Dallas region, for example, there are two large airports, the Dallas/Fort Worth International Airport (DFW) and the Texas Love Field Airport (DAL) which has some airlines connected with George Bush Intercontinental Airport (IAH) and William P. Hobby Airport (HOU) in the greater Houston area. The ridership of these airlines can affect and can be affected by the Texas HSR.

State Government

The Texas HSR project will be constructed within only one state. This reduces the number of actors from the State-level public sector in the planning process; only Texas is involved. In the Government of Texas, there are Legislative, Executive and Judicial branches as is usually the case with the Federal Government and the other States governments. The government of Texas adopts a plural executive branch system, which limits the power of the chief executive Governor by dividing power into plural officers in the Executive Branch. Therefore, the Executive Branch has nine branches, each of which has its own jurisdiction and authority. The Executive Branch also includes Governing Boards and Commissions, which administrate many state agencies. The Texas Department of Transportation (TDOT) is one of these agencies, which has a strong influence on the Texas High Speed Rail project.

・Texas Department of Transportation (TDOT)

The TDOT is a state agency that has the authority of overseeing transportation-related institutions managing highway systems, public transportation, flight industry, and railroad industry. The TDOT also takes initiative of several programs to transform the transportation system in the future. For example, The Texas Transportation Plan 2040 was implemented in 2015 by the TDOT to define the strategic direction of transportation policy in Texas. It includes 25-year long range planning of maintenance and reinvestment in aging infrastructure for every transportation modes [63]. The Texas HSR project between Dallas and Houston is part of this envisioned plan as is the improvement of the other transportation facilities. This suggests the supportive attitude of the governmental agency to the HSR project. The TDOT claimed supportive comments that “risks [of private funding] can be mitigated by promoting policies that encourage high-speed rail ridership, stations that provide cohesive connectivity to other modes of transit/transportation” [64]. The TDOT is also providing technical support and advice to the FRA in conducting the NEPA process for the Texas HSR project. [65]

Because the HSR project has large and broad impacts on various societal issues, any other state agencies, such as Texas Commission on Environmental Quality and Texas Department of Housing and Community Affairs, may affect the construction process or operation of the HSR at some time point in the future. However, each agency has a far smaller impact than the TDOT; thus we consider only the TDOT as the main actor of the State government-level agency in the Institutional Sphere.

Local Government

Besides the power of federal and state governmental agencies, local governments will also have a strong impact on the Texas HSR project in terms of transportation planning and land-use policy. Some of them are supportive of the project, but there is also fierce resistance from other local governments. They include municipal governments of Dallas, Houston and other cities, local counties such as Grimes County, which opposes the project in terms of land acquisition, and metropolitan planning organizations (MPO) of these regions.

・Municipal governments of large cities and local counties

The municipal government has an authority to do long-term planning for the transportation system and to permit construction of the large infrastructure within its area. For example, the City of Dallas has a city-zoning plan to make sure sustainable development happens, and so it can promote the HSR project by admitting the construction of a terminus station adjacent to its business district. In 2016, Dallas City Council approved a Cooperation Agreement with the private entity, TCP, to "facilitate expedited review of this major private infrastructure project through the necessary federal, state and local review processes." [66] The city of Houston also has a Transportation Planning section to analyze and evaluate the viability of any transportation plan. It continues to communicate with TCP in terms of station location and economic development around the station area near the intersection of Loop 610 and Highway 290. Also, it would consider the connectivity improvement plan by the extension of current light rail [67]. Both of these large cities are supportive of the project expecting the future economic growth of the regions. On the other hand, some of the small counties that the HSR line will be passing through have opposed the project, mainly due to the concern with the private property rights of landowners. For example, the Grimes County Commissioners Court has tried to halt the project by passing an ordinance that requires TCP to show the legitimacy of using Eminent

Domain for the private for-profit project [68]. This movement would create hurdles for TCP to complete the land acquisition for construction of the HSR ROW, and it may cause delay to the project like as in the California HSR project [69].

As a result, cooperating with these local governments during the planning process for HSR is essential to ensure the successful and smooth implementation of the Texas HSR.

・Metropolitan Planning Organizations (MPO)

MPO is the political board that has the authority to carry out the transportation planning in the urban areas whose population is over 50,000. There are 25 MPOs registered in the State Government of Texas, which are responsible for local policies of urban transportation planning [70] [71]. The following two MPOs, the population of which is over 200,000, have a significant impact on the Texas HSR project, because their policy-making process could affect the connectivity to both terminus stations of the HSR line.

・Houston-Galveston Area Council (H-GAC)

The H-GAC is an MPO managing the transportation planning in Houston, Conroe, The Woodlands, Lake Jackson, Angleton, and Texas City. The mission of the MPO is to provide "leadership to guide regional development wisely and manage change constructively."[72] For example, the H-GAC is proposing the "2040 Regional Transportation Plan" to cope with the high population growth in this area. When considering relatively underdeveloped public transportation in the Houston area, it is essential for the HSR operator to propose a mass transit system connected with the HSR lines at the terminus station. A feeder transportation system will be needed to secure the ridership of the HSR, and so the decision of the MPO has a large impact on the HSR ridership.

・North Central Texas Council of Governments (NCTCOG)

This MPO manages the transportation planning in Dallas, Fort Worth, Arlington, Denton, Lewisville and McKinney, whose population is now over 7 million and is expected to reach over 10.7 million by 2040. The mission of the NCTCOG is to "assist local governments in planning for common needs, cooperating for mutual benefit, and coordinating for sound regional development."[73] From this standpoint, the NCTCOG is supportive of the construction of the Texas HSR not only between Dallas and Houston, but also from Dallas to Fort Worth to improve further connectivity. The rail connection between Dallas and Fort Worth is considered to be an important feeder system for the HSR, and so the terminus station of the HSR will be constructed near the Union Station of the commuter rail to access Fort Worth.

・Urban Public Transportation Organizations

One of the key factors to reduce total travel time of HSR users is to secure the connectivity to and from the terminus stations of the HSR, whose competitive advantage is its easy-to-access location from the city center. For the sustainable development, mass transit should be implemented to connect the stations with the business district zone to provide sufficient capacity to transport large number of passengers. Thus, it is critical for the HSR operator to appeal to local transportation operators in order to establish high quality and high-capacity transit systems. For the Texas HSR project, the following two organizations can play a significant role in implementing a new or improved transit system connected with the HSR line.

・Dallas Area Rapid Transit (DART) and The Fort Worth Transportation Authority ("The T") [25]

There are transit agencies in Dallas and Fort Worth. Due to their collaborative relationship, Dallas and Fort Worth are connected by the public transportation, such as the Texas Eagle express train operated by AMTRAK and The Trinity Express that is a commuter rail, connecting Dallas Union Station and Fort Worth Intermodal Transportation Center. The DART operates bus, commuter rail, light rail and other transportation systems in Dallas and 12 surrounding cities. [74] The DART has a relatively well-developed transit system as shown in Fig. 4-18, and it also takes an initiative to develop transit-oriented society by planning Rapid Transit Light Rail System in this area. These well-developed networks connect the suburban areas with the business district area at the Union Station, where the terminus station of the HSR will also be constructed. The T in Fort Worth operates several bus networks and the Trinity Express rail in the surrounding area [75]. It is now promoting a new commuter rail project, TEXRail, which connects the DFW airport with the city center of Fort Worth. The accessibility from Fort Worth to the HSR station could be improved by promoting this project.

・METRO Houston [76]

METRO Houston operates bus services and three light rail lines in Houston and surrounding areas as shown in Fig. 4-19. The public transit system in the Houston area is relatively less developed, and therefore it may affect the ridership of the HSR if the terminal lacks the good connectivity with the city center and other residential areas. A new light rail extension is now planned to connect downtown and the HSR station location, but it is uncertain when the construction will begin. As a conclusion, the access to the HSR station in Houston can mainly be by private car, as TCP expects in its "Last Mile Analysis" report. [36]

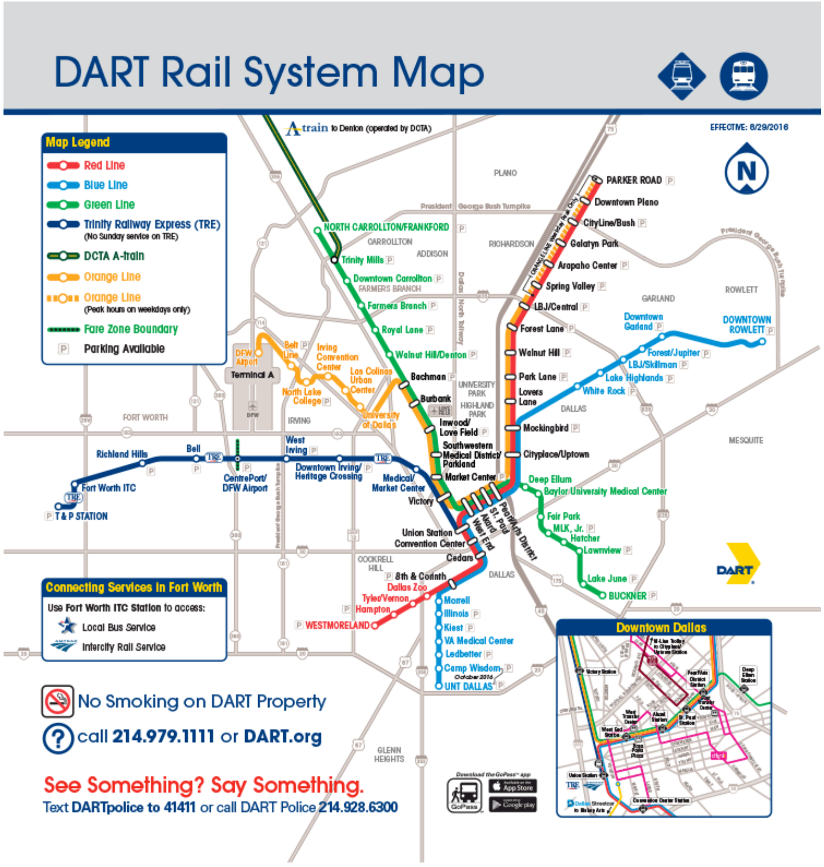


Fig.4- 18 DART rail lines and Intercity Rail between Dallas and Fort Worth

(Retrieved from [74])

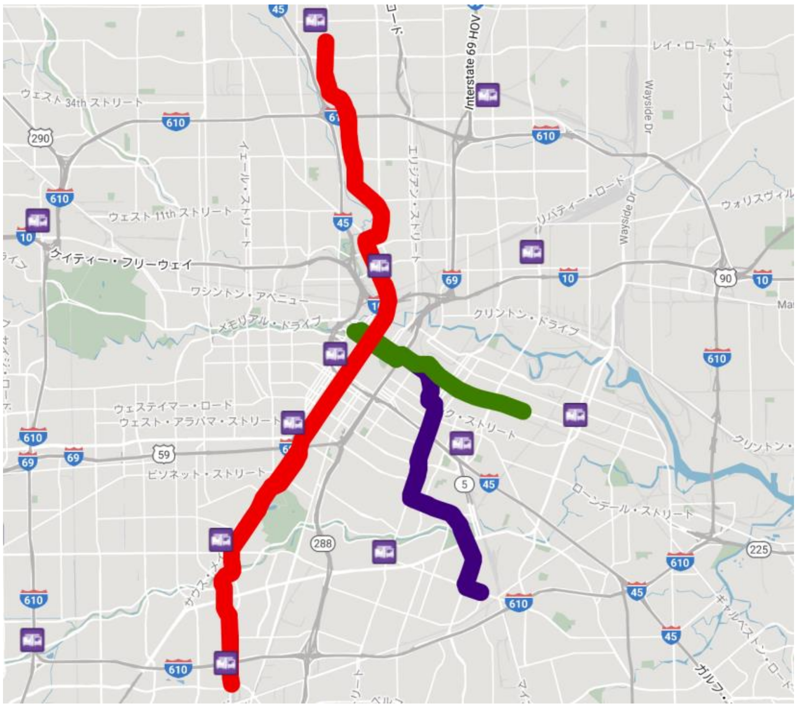


Fig.4- 19 Existing Light Rail (METRO Rail) links in Houston area

(Data Source: METRO Houston [76])

Other Governmental Institutions

・Japanese government

As one of the main economic growth strategies of the Japanese Government, overseas development of package-type, high-quality infrastructure with operational know-how is considered to be important. The government is aiming to revitalize its domestic economy by reaching the large potential market all over the world, as well as to strengthen political and strategic connections with other countries, including the US. The Japanese Government considers the "Shinkansen" system as the foremost technology for exporting, which will result in good economic growth for Japanese manufacturing companies and rail operators [46]. The Texas HSR project has been promoted by the local private entity, TCP, backed by Central Japan Railway as a technical consultant. This project will use the N700-I type rolling stock that is based on the Japanese crash-avoidance system.

・Japan Overseas Infrastructure Investment Corporation (JOIN)

The Japanese Government promotes this project not only by political support, but also by investing in TCP through its owned fund, JOIN. JOIN is the government-private sponsored fund that focuses only on overseas investment of Japanese infrastructure technologies. JOIN has already decided to invest $40 million in the project to support TCP to conduct its construction and survey [42].

Even though the Texas HSR project is funded only by the private sectors, including JOIN, this project is a promising one for not only the US stakeholders, but also the Japanese society. This can help the project to seek further financial aid from any other funding source from Japan, as a foreign investment.

(2) Private Sector

・Texas Central Partners (TCP), LLC

TCP is a private company that intends to bring Japanese HSR technology to build the new HSR line between Dallas and Houston. TCP started the feasibility studies including a business plan in 2014. TCP is mainly established for shaping the project by raising the funds, conducting an environmental impact assessment, and deciding the alignment of the line and stations. The challenge it faces now is raising funds from private investors. Those funds include all of the initial cost, including land procurement cost, construction cost, rolling stocks, and the cost is estimated to be more than $10 billion [38][39][40]. They have tried to persuade Texas-based investors to invest money for the upfront cost by the end of 2017. TCP is the main promoter and organizer of this project, being supported by private investors and technical consultants. The quality of TCP's work directly affects the entire schedule of the construction and HSR's commencement. After finishing construction, TCP will be the main operator of the HSR system. Therefore, TCP is responsible for all the procedures in development, promotion, operation and maintenance phases of the entire project.

・Central Japan Railway (CJR)

CJR is one of the large private rail operators in Japan having originated from Japan National Railway Company, which was privatized and divided into 7 private JRs in 1987. CJR operates rail networks in the central area of Japan, Chubu region. CJR intends to deploy its own "N-700 I Bullet" HSR system overseas. This technology is based on the system actually used in Tokaido Shinkansen connecting the three largest metropolitan areas, Tokyo, Nagoya and Osaka. CJR is now responsible for constructing the new Chuo-Shinkansen line based on the Super Conductive Magnetic Levitation System (SCMAGLEV), which will connect Tokyo and Nagoya in 2027 within 50 minutes [77]. Therefore, CJR is one of the main HSR operators in Japan. In 2016, CJR established a local subsidiary, called High-Speed-Railway Technology Consulting Corporation (HTec), to support TCP by providing technical assistance and advice as a consulting company [78].

・Consortiums of private construction/consultation companies

This stakeholder includes real estate developers, construction companies and consultation companies, such as Dallas to Houston Contractors (DHC), Freese & Nichols, and Arup [78] [79] [80]. DHC is a joint venture of international construction companies which has already done pre-construction cooperation and will be appointed as the main construction company. Freese & Nichols and Arup are the consultation companies that are cooperating with HTec to support the TCP in terms of process management and engineering works of large infrastructure. These companies are mainly interested in the financial feasibility of the project itself, and other potential development of surrounding areas of the HSR line as a result of the new HSR operation.

・Private investors

One of the big challenges that TCP faces is to secure its financing source from the private sector including many private investors. TCP has insisted that there is a potential demand for infrastructure investment not only from Texas-based equity fund, but also global investors outside the US. However, there is limited information about the secured funding from private investors other than the funding which is the result of the first round of fund raising, $75 million, and the $40 million funding from JOIN in 2015. In general, institutional investors, including some private equity funds or pension funds, seek the infrastructure projects that are worth investing in. Recently, "[a] great deal of attention has focused on connecting institutional investors with projects that need their capital," reported by the Mckinsey Global Institute [81]. However, the profit model of large infrastructure businesses is based on long-term perspective. It takes more than several decades to recover all of its heavy upfront cost, which is a cause of uncertainty for the investors. Whether TCP successfully attracts the private capital from those investors has a large impact on the entire schedule, and therefore, the success of the project.

・Land owners

Private land owners could have a large impact on the land acquisition process of the HSR operators. Individual landowners might not be powerful enough to limit the TCP's land acquisition procedure, but their collective actions could hinder the process and cause serious delays in the project schedule. To reduce the opposition to construct ROW on their land, TCP has tried to negotiate them individually by offering reasonable compensation, but there are uncertainties in the prospect. Although the use of Eminent Domain act, that is applicable for the infrastructure project, will be under consideration, this may cause serious dissent in the regions, and therefore TCP wants to avoid using it, considering it as a last resort. It is much more important for TCP to involve these private landowners into planning of the system. Although some of the private landowners are interested in real estate development, a large portion of them is concerned about the required land use for the new HSR ROW construction.

・Political activists

The Texas HSR project has aroused considerable controversy in the US. There have been many pros and cons of the project in terms of its feasibility and necessity. Advocates include the American Public Transportation Association (APTA), which is the largest leading group to advance the public transportation networks in the US [82], US High Speed Rail Association (USHSRA), which is an organization focusing on the promotion of HSR network in the US [59]. There are also several advocates that focus only on the HSR in Texas and offer their support to the TCP's proposal, including Texas Rail Advocates, which is a Non Profit Organization trying to advance the development of HSR networks in Texas [83], and Texas High Speed Rail & Transportation Corp, which has focused on building the HSR "Texas Triangle" network between the major urban areas, Dallas, Houston and Austin [84].

On the other hand, there are several think tanks that criticize the HSR project. For example, the Reason Foundation, promoting Libertarian Principles and funded by the oil industries, published opposition to the Texas project saying, "Dallas and Houston are poster children for big cities where high-speed rail has no chance of succeeding without public funding."[85] Texans Against High Speed Rail is a local coalition group of the people who oppose TCP and its use of eminent domain, supported by landowners and local communities [86]. Their lobbying efforts to the Congress and the State government have a large impact on the decision making in transportation-related policy in the US. It is essential to identify these activists who have interests in the Texas HSR project, and have political and financial influences on the decision-maker in the public sector.

・Aviation industry

The airline industry, which operates flights between the North Texas and the Greater Houston area, is primarily one of the potential competitors of the HSR operator. The potential users of the HSR service are expected to be the passengers who will be diverted from the direct flights between Dallas and Houston. Implementation of the HSR to the Dallas-Houston corridor will likely affect demand for shuttle flights between the two regions. Considering the station locations of the Texas HSR line, it will be unlikely that the HSR and the flight company coordinate with each other from the viewpoint of multi-modal network. As we mentioned in Section 4.2.1, the past plan of the Texas HSR was stopped by the results of lobbying of Southwest Airline, which is the largest low-cost carrier based in Dallas [87]. So far, Southwest has not showed any attitudes for or against the HSR project, but the airline's interests will be potentially affected by the HSR operation. Thus, it is important to consider this competitive relationship between rail and flight industries within the inter-city travel market. On the other hand, the modal share of flight between the two regions is about 5% of all passengers, estimated from the data of the TDOT [88]. More than 90% of direct passengers between Dallas and Houston use the highway, the data shows. Considering the high rate of car ownership in Texas, the competition among the transportation modes are much more fierce between the car industries and the others.

・Airports

The Texas HSR is a single link system to connect between Dallas-Fort Worth and Houston; thus we consider several airports around the North Texas and the Greater Houston areas as stakeholders of the HSR project. In these regions along the HSR line, there are the Dallas/Fort Worth International Airport (DFW), the Texas Love Field Airport (DAL), George Bush Intercontinental Airport (IAH) and William P. Hobby Airport (HOU). The DFW is the primary airport in the North Texas, which is located midway between the city of Dallas and the Fort Worth. It is one of the major hubs for American Airlines, and is the 10th busiest airport in terms of the passenger traffic in the world [89]. DFW welcomed 54 million passengers in 2016, about 70% of which are carried by the American Airlines [90]. DAL is located in about 5 mile northwest from the city center of Dallas. The

DAL is the main hub of the two low-cost carriers, the Southwest Airlines and Virgin Airline. The destination of the busiest route from DAL is the HOU in the Greater Houston area, about 600 thousands passengers in 2016 [90].

The IAH airport is an international airport in the Greater Houston area. It welcomed 30 million passengers in 2016, serving as the hub airport of the group of the United Airlines. The HOU is another international airport located in about 5 miles east from the Houston downtown. It welcomed over 11 million passengers in 2016, most of which were carried by Southwest Airlines. As these two airports in the Houston area are selected as the airports in need of capacity enhancements by 2025 [24], increasing flight demands, both international and domestic, will require the considerable slack capacity and the runway expansion near future. In terms of this point, the Texas HSR project can be a solution to make these airports decide not to spare the capacity for the flights between Dallas and Houston.

・Intercity bus operators

There are several intercity-bus operators between Dallas and Houston. For example, Greyhound is one of the largest providers of highway bus transportation service in Texas. Greyhound Bus Stations are located in the center of business district both in Dallas and Houston, so it provides good access for the business passengers who want to move efficiently between these two cities [91]. These intercity buses provide much slower, but cheaper travel transportation, so passengers who have relatively low value of time, as mentioned in following sections, tend to choose the bus services. If the Texas HSR operator wants to attract the same target in the markets, these bus operators will be potential competitors in the future.

(3) Transport Users

For the purpose of this research, it is useful to categorize intercity passengers into two stakeholders: business users and private travelers. Because the Texas HSR is a single link line between two large cities, commuters are not main actors affecting this system. Also, this line uses dedicated tracks for passenger rail, so the freight users are not affected by introducing this rail line. Therefore, we should consider only two categories as transport users.

・Intercity business passengers

The intercity business passengers represent the stakeholders who travel between the Dallas-Fort Worth area and the Greater Houston area for the purpose of business. They mainly travel by personal car, intercity bus or flight (there is no passenger rail service between the two cities so far). In general, these passengers have higher value of time, which means they are willing to pay expensive fares to save the travel time. They tend to choose the reliable transportation mode that is not affected by congestion or inclement weather. They frequently change their schedule of travel just before the planned departure time, so it is desirable for them to be able to change their reserved seat at the last minute in their schedule. In terms of these aspects, the Japanese-type HSR system, which has high frequency, high capacity and high reliability, is favorable for them. Therefore, the business passengers seem to be the main target of the HSR market. However, due to lack of direct passenger rail services between these regions at present, the business passengers are not familiar with intercity rail services so far. Divergence from other modes to the new HSR is the key factor to secure its ridership, as the competition between transportation modes get fierce.

・Intercity private passengers (leisure, private use)

The intercity private passengers focus more on the price of the fare. They are not as sensitive to time saving and reliability as business travelers. They do not need convenience of schedule change at the last moment, and they do not put much value on comfort inside the vehicles. Considering the highly developed and low fare highway system in Texas, the intercity private passengers prefer to use private cars until people cannot tolerate the serious congestion of the road. From the long-term viewpoint, it is necessary for the HSR operator to capture the needs of these private passengers to expand the market.

4.2.5 Prescriptive Treatment for Physical Domain and Institutional Sphere

Now that we finished the system representation stage of the CLIOS process by identifying the five subsystems in the Physical Domain, the Institutional Sphere, and their linkages, we start the next step. Each of the subsystem is modified for the special conditions in the Texas project, so we can deeply understand "the structural complexity" [4] of the HSR system, and also the different characteristics of the project from other HSR projects in the world. In this section, as a last step in the representation stage, all of this complicated information will be simplified to identify "high-impact paths and networks in the CLIOS Representation" as new findings of the research [4]. Therefore, this step is "the transition from a descriptive to prescriptive treatment" [4] of the HSR system, which implies further improvements of the system.

Fig. 4-20 shows the high-impact network derived from the Transportation Subsystem and the Multi-modal Transportation Subsystem. This diagram is simplified to clearly capture the characteristics of the Texas HSR system. Vehicles, Frequency, Nodes and Linkages are bound together in one circle of Transportation Infrastructure as the "TCP's own decision." The main actors that strongly affect components in the subsystem are shown in blue characters. Their linkages to the components are the Class 2 links, which are depicted by broken arrows in the diagram.

First, there are two feedback structures in this diagram shown in blue circular arrows. Loop 1 shows the positive feedback loop of the reinvestment in Vehicle, Frequency, Nodes and Linkages. Loop 2 also shows the positive feedback loop of the improvement process of the Transportation Service. These loops show that if the sufficient Transport Revenue can induce further Private Investment, it will be used for reinvestment and for service improvement. This enables TCP to concentrate on reinforcing their competencies. This process strengthens the HSR's advantages in Trip Attributes, and therefore, enhances the competitiveness of the HSR with other competitors.

Secondly, the number of stakeholders that affect these positive loops is very small. Because the HSR is funded only from the private sector, the public entities are excluded from these reinvestment cycles. The managerial decision is simple for TCP. TCP can easily pursue the profitability of the HSR operation, and it is not strongly affected by public sectors from the financial viewpoint. The private operator can decide how, where and how much these investments should be spent.

Finally, the high rate of Car Ownership in Texas can affect the system both in positive and negative ways. Private cars can enhance the Connectivity of the people who do not have an access to the public transportation, to the terminus HSR stations with large parking facilities. Therefore, in this case, the high rate of Car Ownership might improve the Trip Attributes of the HSR if it integrates the HSR into park and ride system. However, too much usage of private cars to access the stations can cause serious congestion around the stations, and it may deteriorate the Trip Attributes of the HSR due to the uncertainties of the total travel time. Therefore, the fraction of public transportation users is an important indicator to see how effective Intermodal Integration Policies of Local Municipalities is.

As a result, the Texas HSR system can be improved as follows:

・To secure simple decision making by TCP to reinvest in transportation infrastructure and service improvement process is the key to enhance the advantages of the HSR

・Modal split, which is affected by the competition with other modes, is the essential indicators to see the profitability of the HSR (in terms of Transport Revenue)

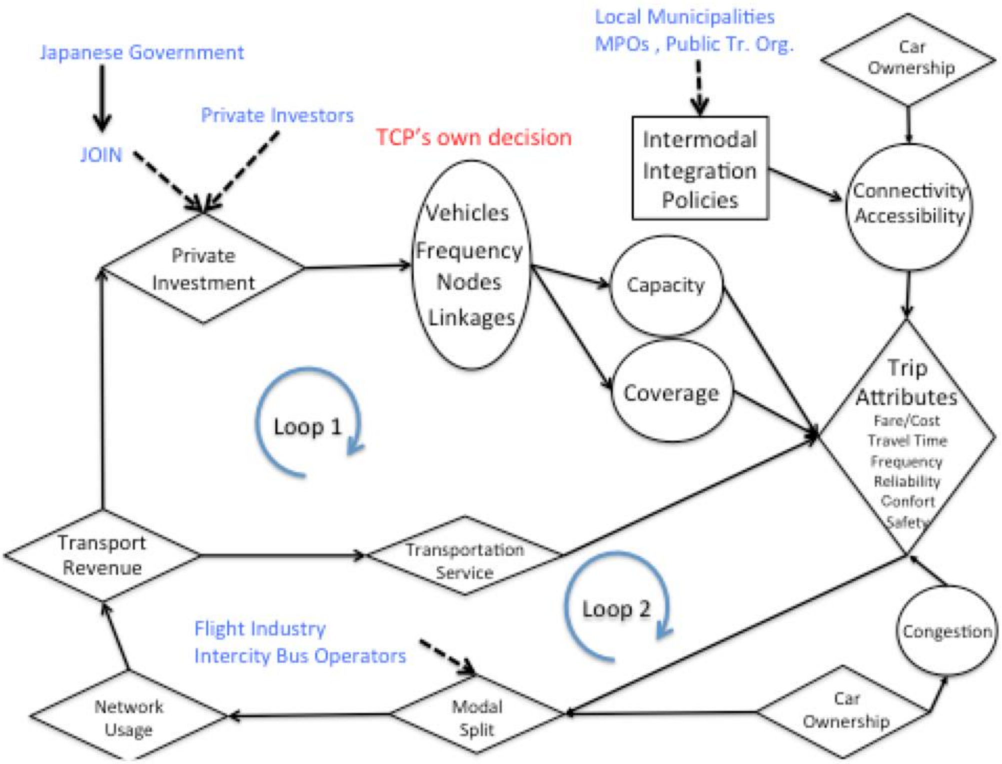


Fig.4- 20 High-impact network derived from the Transportation Subsystem and the Multi-modal Transportation Subsystem

4.3 Findings and Conclusions from the Representation Stage

This chapter introduced several characteristics of the Texas HSR system through the representation stage of the CLIOS process. First, it introduced five subsystems in the Physical Domain, which were depicted in two ways: first for the general HSR system, and the second specific for the Texas HSR project. Comparing these two diagrams clearly emphasized the differences between the general and the Texas HSR project. Next, it explained some of the actors in the Institutional Sphere and discussed their influence on the Subsystems in the Physical Domain. Finally, the high-impact network is derived from the Transportation Subsystem and the Multi-modal Transportation Subsystem specifically modified to identify the important key factors to success. There are several conclusions from this Chapter as follows:

・One of the most important characteristics of the Texas HSR is its finance. There is no US government public funding or investment to financially support the project in terms of construction, reinvestment and operation cost. However the government of Japan may be an investor. This characteristic softens the political interference on the system.

・Profitability from the operational revenue will induce further private investment. This will be used to reinvest in the Transportation Infrastructure and to improve the Transportation Service. Further improvement in these two aspects can reinforce the strength of the HSR and competitiveness with other modes.

・Competition with other modes, especially with highway users, is the threat for the project to secure the high ridership and profitability. Modal share of the HSR, therefore Modal Split, is an important indicator for the project to check its advantage over other modes.

・In addition to difficulty in funding, there is an uncertainty about the prospect of land acquisition for the construction of the HSR due to the opposition from some actors in the Institutional Sphere (local county and landowners, for example). Various stakeholders have influence on Land Supply, and consequently, Land Cost. The key to the success is how to justify the use of Eminent Domain arguing that the project serves the “public good” even though this project is for-profit.

As findings from this chapter, in the Texas HSR project, there is a tradeoff between two aspects:

> The advantage is that the privately financed scheme can enhance the freedom of managerial decision-making for the private entity. Its freedom of actions enables the company to pursue the profitability by re-investing in its infrastructure to make the most of the competitiveness of the HSR; and

> The disadvantage is there are uncertainties in land acquisition, because it is much more difficult for the Texas project to justify the right of Eminent Domain than for the publicly funded, non-profit projects to justify it. The private entity should emphasize the “public good” of the system since it will provide reliable inter-city transportation service and make profit at the same time.

Now the question is, “What are the competencies of the HSR system? Which aspects of HSR should be enhanced to make the advantages more strong?” In the next chapter, we will discuss the characteristics of the HSR, comparing it with other modes of transportation to make it clear what the HSR operator should focus on.

Chapter 5 Characteristics of HSR System as a Transportation Mode

In the previous chapter, we investigated the overall environment surrounding the Texas HSR project through the CLIOS representation stage [4]. We identify the characteristics of the project by analyzing how each "actor" in the Institutional Sphere affects each component in the five subsystems of the Physical Domain, and how the components interact with each other. Based on this analysis, we conclude that the key success factor is to stably increase ridership and secure profitability. Compared with other publicly funded HSR projects, the private operator has more freedom of choice to pursue its profitability by improving trip attributes, such as travel time, operation frequency, safety, comfort, and so on. Therefore, reinforcing HSR's competitiveness with other travel modes is the essential factor for the operator to be successful in the intercity passenger market. The main competitors are airline industries and highway, which dominate the transportation market in Texas. Before considering the competitive strategies of the HSR, we should address the following questions: Is there a potential chance of success for the HSR system to attract passengers in the car-oriented society? What are the essential strengths the HSR system has to compete with other modes?

In this chapter, we conduct comparative studies of HSR system, which are introduced as the first "Ornament" of the CLIOS Process. Firstly we analyze the advantages of a general HSR system from the viewpoint of competition in an intercity passenger market. Before going into the specific case in Texas, it is necessary to consider what general roles the HSR should play in a comprehensive transportation system. Based on literature reviews, we organize and compare various trip attributes of each transportation mode in terms of modal share and its main attributes. Next, we compare the specific characteristics of the Japanese Shinkansen system with other types of HSR systems to further understand the technological advantages of the Texas HSR. As a result, we can identify key findings to make the project successful, which are relevant to the systemic goal that the Texas HSR project should pursue in the future.

5.1 Competitive Advantages of a General HSR System

In this section, we discuss characteristics and competitive advantages of a general HSR system compared with other modes. First, modal share in a transportation market is discussed to clarify in what conditions we can take advantage of HSR's characteristics, in terms of distance and travel time. As a next step, we compare main trip attributes of each transportation mode to understand relative advantages/disadvantages of a general HSR system. These discussions are based on a review of various literatures.

5.1.1 Modal Share

There is a considerable number of researchers pointing out the importance of a multimodal transportation system, which is a mix of road, rail, air, and other modes mutually connected, as an essential infrastructure to foster regional development. An intercity passenger rail system is always one of the essential elements to establish a well-balanced transportation network [92]. Morichi argued that desirable transportation networks in and between megacities are mainly structured as "hierarchical network[s]" of rail and road. In the paper, the "hierarchical network" of rail was defined as a network of intercity HSR, suburban heavy/commuter rails and urban rails (subway, light rail and others) connected with each other. He claimed that the long-term planning of rail-based public transportation and road network is essential to provide a well-balanced transportation system to support the stable growth of the megaregions [93]. His argument based on Asian cities was consistent with the case in the Northeast Corridor (NEC). In the argument of the NEC Future, which is a "comprehensive planning effort to define, evaluate, and prioritize future investments" mainly in passenger rail industries, the importance of rail's connectivity and accessibility with other modes in the comprehensive transportation networks was underlined [17]. Amano segmented passenger transportation market based on trip purposes (business, commute and private), travel distance, city size, inter/intraregional and urban/suburban transportation. He categorized the suitability of each transportation mode in each segment. Considering characteristics of each mode, he claimed that the key role an HSR should play in the comprehensive transportation system is to provide high capacity and connectivity with a main artery between large cities of 100-500km (60-300 miles) [94].

Fig. 5-1 shows the estimated modal split of transportation modes in each trip distance in Japan. The blue line shows that the modal share of various railroads, including conventional rails and HSRs, is over 50% when the travel distance is between 200 and 400 miles. The rail network in Japan is well developed for main arteries all over the country as well as road and flight networks [94].

People can choose their preferred modes from short to long distance; therefore travel mode seems to be selected by travel distance. When the trip distance is shorter than 200 miles, more people tend to choose automobile. On the other hand, when the trip distance is longer than about 450 miles, the proportion of flight users exceeds that of rail. This graph shows that railroad, including HSR system, has a suitable range of intermediate distance when it competes with both road and flight. Fig. 5-2 shows the estimated rail share of two megaregions connected by HSR lines in Japan, including Tokaido-Sanyo Shinkansen corridor (connecting Tokyo, Nagoya, Osaka, Hiroshima and Hakata) and Tohoku, Joetsu and Nagano Shinkansen corridors. In most cases that the travel distance between two regions exceeds 200 miles, the modal share of rail users gets higher than 50%, and most of them are presumed to be HSR users. J.M. Urena et al. indicated that the modal share of HSR against car users exceeds 50% when the travel time by road reaches over 2 hours and HSR travel time is around 1 hour, and also the HSR modal share against flight remains over 50% if the HSR's travel time is under about 3 hours, based on their research in European HSR systems [95].

Now the question is, can we change the modal share by an implementation of a new HSR system? The International Union of Railways (UIR) reported two cases of drastic modal shift in Europe. The Paris-Brussels HSR line (200 miles) shortened the travel time from 3 hours to 1.5 hours and it resulted in the modal shift mainly from automobile to the rail, whose modal share changed from 24% to 50%. The HSR line between Madrid-Seville (295 miles) changed the modal share of rail from 33% to 84% in the passenger market that had been dominated by airlines, by cutting travel time of the rail from 5 hours to 2 hours and 10 minutes [96]. Fig. 5-3 shows the comparison of passenger distributions of two European HSR cases, Paris-Lyon (264 miles) and Madrid-Seville (292 miles), before and after the implementation of each HSR line (these figures are created from two data sources, [97][98]). The modal share of rail increased drastically right after the HSR implementation and the total intercity passengers increased in both cases. These results showed that the modal share could be changed by the newly introduced HSR, not only attracting existing passengers from road and flight, but also inducing new demand.

From these results, an HSR system seems to have strong competitiveness with other travel modes when it connects two regions in a suitable range of trip distance, which is about 200-400 miles in general. Within this range, an HSR can attract passengers from other modes even though it is introduced in the market dominated by the existing airline or highway. In Texas, the distance of the proposed HSR is 240 miles between Houston and Dallas, which is within this suitable range for a HSR system to attract passengers from other transportation modes.

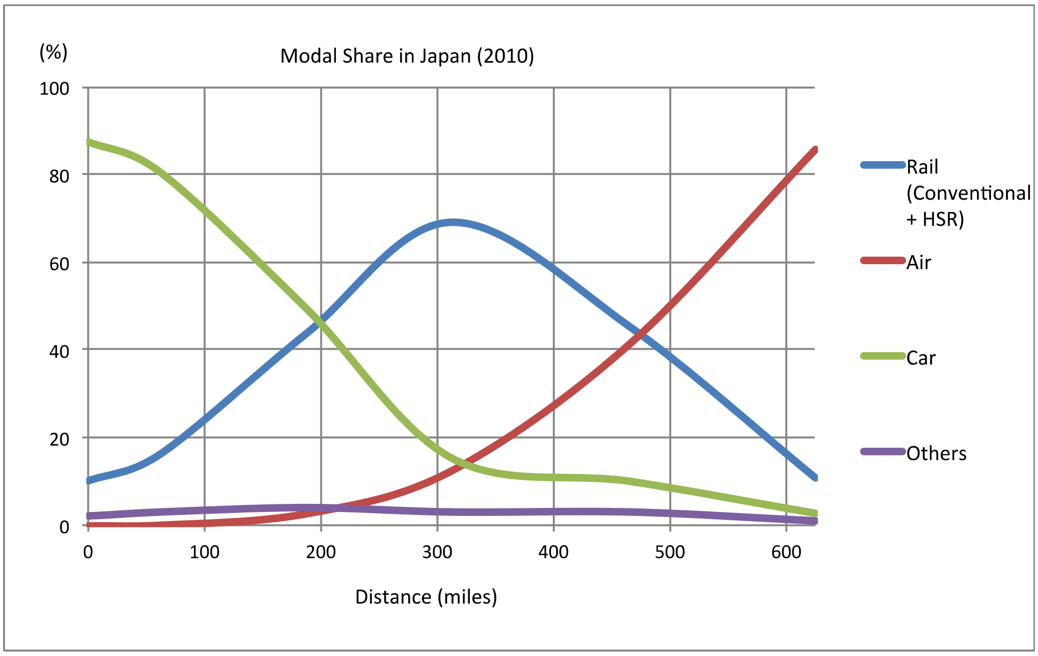


Fig.5- 1 Transportation Modal Share in Japan

(Data source: MLIT, 2010, Using data of [99])

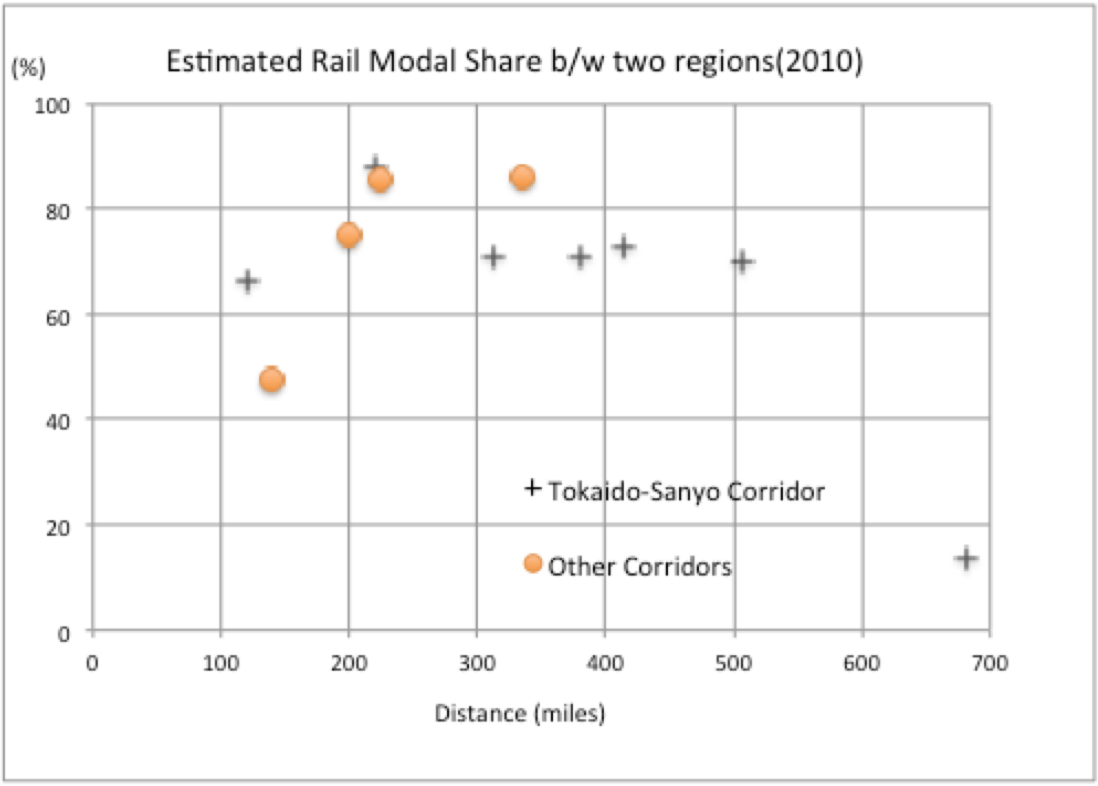


Fig.5- 2 The modal share of rail between two regions connected with HSR in Japan

(Data source: MLIT, 2010, Using data of [100])

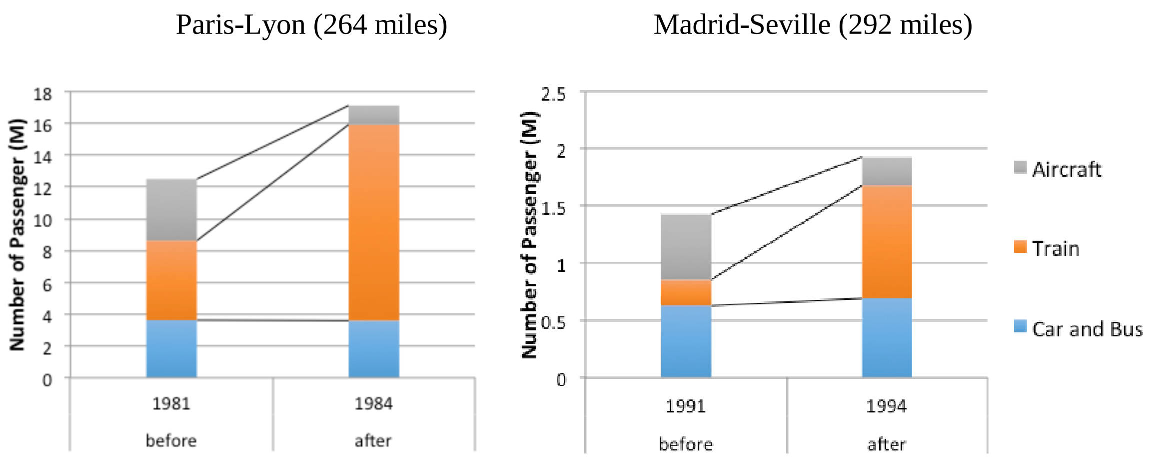


Fig.5- 3 Passenger Demand and Modal share comparisons between before and after of the implementation of the European HSR

(Data Sources: [97][98])

5.1.2 Main Attributes of an HSR System

The competitiveness of an HSR system with other modes as discussed in the previous section is a result of several trip attributes. These attributes are widely discussed in numerous studies of various HSR systems, mainly compared with flight and road. When it comes to attributes that directly affect passengers' mode choice based on their own interests, the following six attributes are frequently discussed in previous studies: Speed, Accessibility, Capacity, Frequency, Safety and Fares [2] [12] [13] [97] [98] [101][106].

We should note that an HSR system has various types of both positive and negative externalities, such as a "spatial impact and possible social and economic impact", and environmental impact such as "local air pollution (LAP)" noise, land acquisition, and so on [97]. These externalities have a large impact on HSR projects' feasibility, and thus should be seriously taken into account. However, these externalities do not directly affect HSR's ridership or its modal share from the viewpoint of actual HSR users. In terms of HSR competitiveness in the intercity passenger market, discussion of these externalities is out of the scope of this chapter, although these impacts must be considered when assessing the feasibility of new HSR implementation.

Speed & Accessibility:

These two attributes are relevant to total travel time of HSR users. Speed is a factor that directly affects travel time on board line-haul (airplane, HSR, bus, etc.) [102]. In general, aircraft is the fastest vehicle with regard to average speed. Todorovich et al. argued that when the trip distance is longer than about 600 miles, flight is more competitive than other modes because time on board airplane is much shorter than that of rail and automobile [13]. To compete with airplanes, HSR technology has been advanced all over the world. Givoni argued that there had been modern HSR systems that can run over 220 mph (350 km/h), but an extremely high-speed rail is usually not feasible due to noise, energy consumption and other technical challenges [97]. It is obvious that there is a technical speed limitation for a conventional HSR, which uses adhesion between iron wheels and a rail (that is why MAGLEV could be an innovative technology to break this speed limit) [103]. Muto et al. pointed out that passengers choose their transportation mode based on total travel time, which includes not only time on board but also access/egress time between station or airport and origin or final destination. Muto et al. also claimed that the passengers' mental burden is greater for access/egress time than that of the same amount of time for line-haul; thus accessibility is an important determinant of mode choice [102]. Of course, as Chen pointed out, the inconvenience of access to an airport from business districts could be offset by the much faster speed of airplanes [104]. However, an HSR system could realize better accessibility than air travel by locating stations in urban centers or providing seamless transportation network connecting stations to the origin/destination. Therefore, accessibility to the HSR station is one of the key factors to improve HSR's competitiveness with airlines besides fare, reliability and so on.

On the other hand, as discussed in the previous section, an HSR system competes with road transportation in trip distances under 200 miles. Vickerman argued that it is obvious that the convenience of door-to-door "travel by a single mode with higher comfort characteristics" often provided by a private car has a great impact on competition between the rail and the road [101]. A trip by private car provides direct connection between origin and destination. Therefore, shorter "door-to-door trip time" with regional "transit connection" is a key factor for HSR to compete with automobiles, especially when the trip distance is under 200 miles [2]. As a result, connectivity to a local transportation network is important for HSR to attract passengers from road industries.

When considering the nature of an HSR system, it competes with flight and road in different trip distances, and accessibility is always critical for HSR to compete with both modes. Vickerman pointed out that "quality of access network" should be a competitive edge of HSR [101]. Therefore, an HSR operator should determine its station locations considering how it can embed the HSR line into a comprehensive transportation network in the region.

Capacity & Frequency:

Capacity is a supply side variable of transportation modes, and it means the number of available seats when it comes to the HSR and airline industries. In general, high capacity leads to high service availability of public transportation, and therefore increased customer convenience. Frequency is also directly relevant to passengers' convenience because it affects the average wait time and time slot. Capacity and Frequency are closely connected, because capacity increase is realized either by frequency increase or average seat expansion per unit vehicle. But the increase in frequency of transportation service brings more utility to passengers, because passenger convenience improves due to a shorter time to wait for the next vehicle and expanding freedom of time slot choice.

Railroad, including HSR, is generally referred to as a transportation mode that provides high capacity. Slow Streets, an advocating group of researchers claiming the efficient use of road traffic, estimated the number of passengers who can go through urban space on rail with unit width per hour to be 11 times higher than private car and 2.4 times higher than bus [105]. One of the main objectives of implementing new HSR lines has been to utilize its high capacity and mitigate the capacity constraint of existing rail, road and flight networks between large cities [101]. Albalate argued that the motivation of implementation for a new HSR line should be "solving congestion in corridors between large populated cities" by utilizing HSR's high capacity [98]. Todorovich et al. claimed that it is possible for an HSR system to "divert a large share of passenger rail service to new" HSR service and to "free up capacity" of the conventional rail for other purposes such as commuter or freight transportation [13].

The reasons why HSR can provide higher capacity and frequency than other intercity transportation modes are mentioned in several studies. Givoni pointed out that one of the reasons is the results of large seat capacity per unit vehicle of long train sets and relatively shorter headways, which is a consequence of HSR's high speed and advanced signaling system [97]. Yasutomi mentioned that HSR's cost structure is characterized as "fixed-cost intensive." He claimed that variable cost increase due to the frequency increase is relatively small; therefore it is easier for the HSR operator to decide increasing operation frequency according to ridership growth [106]. HSR's ability to provide high capacity and frequent service is strength of HSR system that improves its competitiveness with other transportation modes.

Safety:

Safety is one of the most important aspects that should be secured when considering the social benefit of a comprehensive transportation system, the USDOT claims [107]. There are several comparative studies about safety issues comparing different transportation modes. Fig. 5-4 shows the fatality rate of different transportation modes based on the data of the US National Safety Council [108]. When comparing each mode, a rail fatality rate of a unit passenger-mile is about one-fifteenth of that of private automobile (although it depends on load factor). Savage analyzed the fatality risk of different transportation modes. The results showed that over 90% of the transportation-related fatalities in the US happened on highways; about 75% of the fatal accidents on highways were caused by automobiles; a fatality rate on suburban highways is 2.7 times higher than that of urban highways due to the higher average speed and low quality equipment (e.g. street lamp) [109]. The safety of rail is much higher than that of road.

On the other hand, the fatality rate of railroad is 5 times higher than that of domestic airline in the US, based on the data of National Safety Council. Savage mentioned that the fatality rate of long-distance rail is about 6 times higher than that of airline, but these data included the fatality of trespassers mainly at crossings, which consists of two thirds of the fatal accidents [109]. Based on this report, the article of Harvard Kennedy School mentioned that when these trespassing accidents are excluded, the fatality rate of train decreases drastically [110].

In terms of a HSR system, several researchers pointed out the superiority of its safety over other modes. Campo et al. argued that an HSR is apparently the safest transportation mode together with flight, because of their lowest fatalities rate of passengers. They concluded that the safety cost of HSR has been already included in the large upfront cost and high standard of maintenance costs. [111] Janic compared safety, defined as “the risk of death during an accident,” of high speed transportation systems including HSR and aviation. He estimated the safety of an HSR system as higher than that of aviation based on the historical data [112]. Mori mentioned that HSR system is made safer than an “already safe” conventional rail by adopting dedicated and fully separated tracks equipped with specially applied signaling system [113].

As an overall result, rail is a much safer transportation mode than automobile, and the safety level is further strengthened for HSR system. These results show that the safety condition of the intercity transportation system is improved by the modal shift from highway users to HSR. From the viewpoint of the public sector, the economic loss due to traffic accidents decreases when the rail increases its modal share in the transportation market dominated by the road industries.

Fares:

Fare is one of the most important factors that directly affect the mode choice of the passengers. People makes decision to pay expensive fares based on their Value of Time (VOT), which is how much they value their own time in terms of travel time saving. In general, HSR is exposed to price competition with airline industries, both of which provide high-speed transportation method to mainly long-range travellers in exchange for relatively expensive fares. Yasutomi considered the dynamic pricing strategy for the proposed MAGLEV train, which will connect Tokyo and Osaka about 60 minutes competing with not only airline but also conventional HSR, Tokaido Shinkansen [106]. He concluded that competitive price is determined relative total travel time and passenger's willingness to pay of transportation fares, and thus dynamic pricing could be effective way to attract a wide range of passengers for suitable transportation modes [106]. HSR's fare should be set at the value that could attract sufficient number of passengers by justifying its time saving effect and other attributes such as safety, as discussed above.

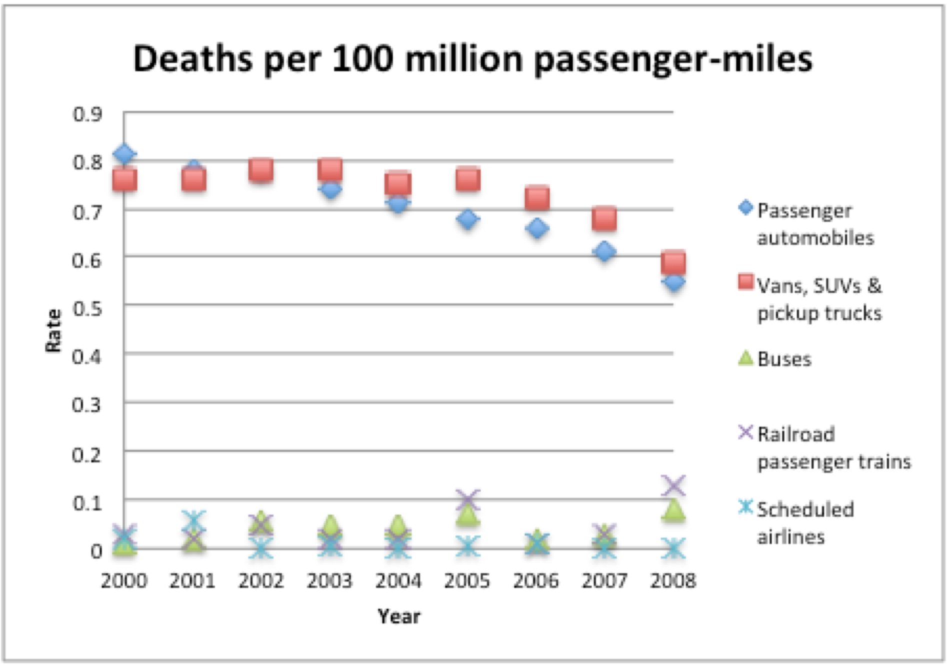


Fig.5- 4 Comparison of fatality rate of different transportation modes

(Data Source: National Safety Council [108])

5.1.3 Findings from Previous Comparative Study

Based on the analyses above, we compare the suitability of each transportation mode for each purpose and distance. Then, we evaluate the main trip attributes relevant to competitiveness of an HSR by comparison with other modes. These results are shown in Tables 5-1 and 5-2.

In Table 5-1, we divide the transportation segment into two large categories: Interregional transportation and intraregional transportation. The former is transportation that connects two or more metropolitan areas, and the latter is transportation that operates within one metropolitan area [17][93]. Interregional transportation is divided into four segments based on trip distances, and the intraregional transportation is segmented into three subcategories (Metropolitan, Commuter and Transit). Flight is the most suitable mode for long-range categories (>400 miles) due to its highest speed. Each of the three types of rail system (HSR, Heavy Rail and Light Rail) has specific strengths in each category: the HSR system is most suitable for middle to long range (200-400 miles) due to its higher speed compared with other types of rails and automobile, and better accessibility compared to flight. Heavy rail is mainly used as a part of a mass transit system for a 25-50 miles trip distance within a metropolitan area, and light rail is suitable for the shortest trip range of transit especially under 10 miles (these mile settings are determined by referring to [2]). Automobile is suitable for short to middle–range, especially for commute and transit purposes. For trip distances longer than 200 miles, automobile is less competitive with HSR in terms of timesaving (but the cheaper cost is attractive for passengers who place a low value on their time).

In Table 5-2, key attributes are compared for each transportation mode except fares. HSR system’s primary advantage is that it can save travel time for middle to long distance trips, due to its higher speed than automobile and conventional rail. HSR can substitute airline in even longer range trips only when better accessibility is secured from city center to its stations than to airports [97]. As is the case with all railroads, HSR can transport more passengers than roads and airlines utilizing its large capacity as discussed in the previous section. Higher safety than existing road networks is also an advantage of an HSR system that can attract passengers from the road.

Table 5- 1 Suitability of each transportation mode for different range of trip distance

Purpose & Range / Transportation mode		Interregional (Intercity)Transportation				Intraregional Transportation		
		Over Long Range (600miles–)	Long Range (400–600miles)	Middle Long Range (200–400miles)	Middle Range (50–200miles)	Metropolitan (25–50miles)	Commuter (10–25miles)	Transit (2–10miles)
Flight		◎	○	△	–	–	–	–
Railroad	High Speed	△	○	◎	○	△	–	–
	Heavy Rail	–	–	△	○	◎	○	△
	Light Rail	–	–		–	–	△	○
Automobile	Bus	–	–	△	○	○	◎	○
	Passenger Vehicle	–	–	△	○	○	◎	◎

◎: Frequently Applicable ○: Applicable △ : Not Frequently Applicable - : No Means

Table 5- 2 Comparison of utilities of each mode

Characteristics / Transportation mode		Trip Attributes				
		Speed	Accesssibility	Frequency	Capacity	Safety
Flight		◎	△	△	△	◎
Railroad	High Speed	◎	○/△	◎	◎	○/◎
	Heavy Rail	○	○	◎	◎	○
	Light Rail	△	◎	○	○	○
Automobile	Bus	○/△	◎	○	△	△
	Passenger Vehicle	○/△	–	–	×	△

◎: Strong Advantage ○ Modest Advantage △: Intermediate ×: Disadvantage

(Both tables are created by the author)

5.2 Comparison of HSR Systems

The definition of HSR varies in different countries. One of the definitions is provided by the USDOT as follows:

"Frequent, express service between major population centers 200–600 miles apart, with few intermediate stops. Top speeds of at least 150 mph on completely grade-separated, dedicated rights-of-way" [6]

As the International Union of Railways (UIC) claimed, the general view of HSR is "a combination of a lot of elements which constitute a whole system" to achieve much higher speed than conventional rail. UIC claimed that an HSR system should use specially constructed trucks, specific signaling system and other equipment to ensure safe operation [114]. Based on these common perspectives, different design concepts of each HSR system provide different characteristics. It is important to understand HSR system's specific features before implementation. For the Texas HSR, the operator will use the Japanese Shinkansen technology as a whole system, including rolling stocks, tracks, signaling system, power supply equipment, control center, and so on. In this section, we identify the specific characteristics of the Shinkansen technology by comparing them with those of European HSR systems (such as French TGV, Spanish AVE and German ICE).

・"Crash Avoidance" principle [34]

The main characteristics of the design concept of the Japanese HSR system is called "Crash Avoidance," which uses physically separated dedicated tracks and fully sealed lines without any crossings as shown in Fig.5-5. "Automatic Train Control (ATC)" is a signaling system that prevents collision between trains [34]. As shown in Fig.5-6, ATC automatically brakes and decreases the train speed under threshold speed to prevent any collision between train cars and derailment due to excess speed on any curves. By adopting this concept, there is nothing that can hit the operating train in the sealed area, and therefore it has no theoretical possibility of physical collision. On the other hand, the European HSR system broadly adopts the mixed-use of HSR with conventional and freight rail on the same tracks [13][85]. This style can reduce the upfront cost to construct the tracks by using a shared rail with another rail system, but it should consider the crash with other non-high-speed rolling stocks on the rail. Therefore, it should enhance the impact resistance of rolling stocks, which makes them heavier and larger. To support these heavy train sets, large structure of the rail, bridge and other infrastructure are required. In addition, freight rail is generally heavy and causes more damage to the rail than passenger trains; therefore the cost of maintenance can increase. Compared with European HSR system, the Japanese “Crash Avoidance” principle enables the rolling stocks to be lighter, and thus more compact, so that the lifecycle cost of the system seems to be lower than that of the European HSR system, even though the upfront costs of constructing new dedicated lines is significant [34].

From the viewpoint of operation management, the Japanese HSR system has following advantages:

・Dedicated tracks exclusively for passenger trains can increase operation frequency as it avoids getting stuck behind low-speed trains (This constraint is often mentioned as a disadvantage of shared-rail systems). Therefore, it can flexibly change its frequency according to ridership variation on a daily, weekly and annual basis, and it can adjust the high-density transportation between several large cities.

・It is possible for the train operator to reduce the energy consumption and maintenance cost due to the light weight of rolling stocks even though they are used frequently. Therefore, frequent operation increases less its operation cost compared with another type of HSR system.

As a result, construction of a fully-sealed dedicated track requires a huge upfront investment, but the lighter rolling-stocks make it possible to reduce maintenance and energy costs; therefore the Japanese system can reduce the total life cycle costs in the long run. This characteristic is suitable to increase the operation frequency and capacity according to ridership growth, as seen in the 7 routes in Japan (Tokaido, Sanyo, Tohoku, Joetsu, Hokuriku, Kyushu, and Hokkaido) and one route in Taiwan (Taipei-Kaoshun), which use Shinkansen technology. From the long term perspective, a key factor to success of the Texas HSR operator is how to utilize these advantages of high capacity and frequency to realize stable ridership growth.

Fig.5- 5 Dedicated trucks of Shinkansen HSR system

(Retrieved from [34])

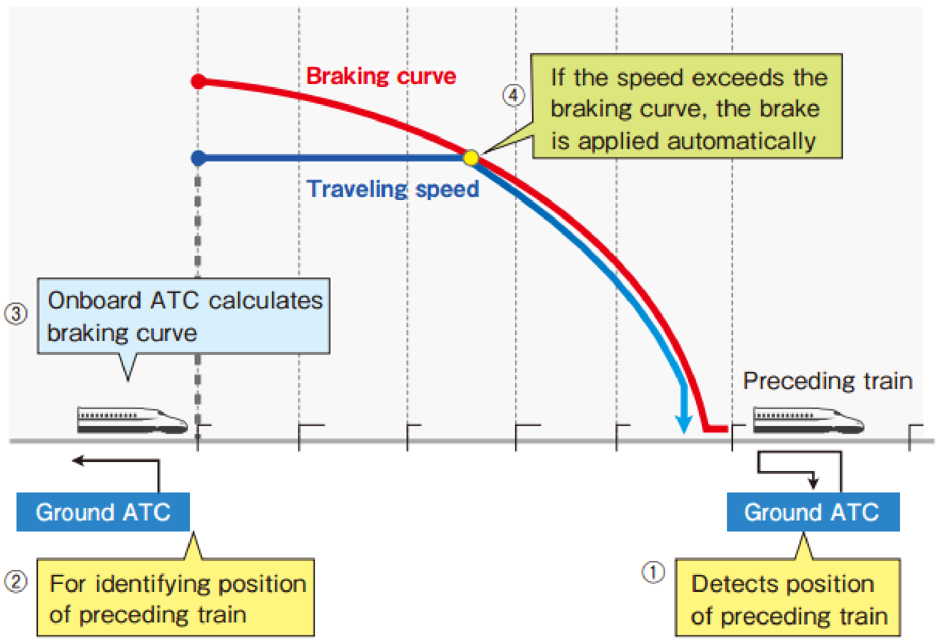


Fig.5- 6 Automatic Train Control of Shinkansen system

(Retrieved from [34])

5.3 Conclusion

In this chapter, firstly we discuss modal share in a passenger market of various trip distances, and identify that when a HSR line connects two or more highly-populated regions 200-400 miles away, a HSR can attract a large portion of passengers from the market. As several European cases show, a new implementation of an HSR system with the suitable market condition could drastically change the modal split in the existing intercity passenger market [96] [97]. Therefore, the proposed Texas HSR, which is 240-miles long between Houston and Dallas, should be a promising project by attracting passengers from other transportation modes, especially from highway users. Then, we consider what advantages an HSR system has in terms of competition with other transportation modes. In general, a HSR system has primary advantages of high speed, large capacity, safe and convenient service. These features are compared with other modes in Table 5-2.

Next, in Section 5.2, we discuss what the specific advantages of the Japanese Shinkansen system are, compared with other types of HSR systems. The main characteristic of the Japanese system is called, "Crash Avoidance" principle, which uses dedicated tracks and the speed controlling system that prevent any collision between the HSR trains [34]. On the dedicated line, all of the trains are operated in the same speed range and they have a unified braking system. These technical aspects can launch several trains in a short headway, and thus realize high frequency operation [34]. Based on these characteristics, we find that the advantage of the Shinkansen system is its ability to provide flexible frequency according to travel demand, which can enhance convenience of passengers that further attracts users from other modes.

From the historical lessons, implementing a HSR system to mitigate high burden on the existing highway and airline networks could be successful in terms of economic/social benefit [98]. In Texas, one of the main objectives of introducing the HSR system is to reduce the traffic congestion on its highway network; therefore it is important for the HSR operator to take advantage of its high transportation capacity to attract a wide range of intercity passengers in the car-oriented society. The Japanese HSR technology enables the operator to flexibly increase frequency and capacity according to ridership growth, utilizing its technical advantages. Of course, the increase in operating cost should be taken into account to make the project profitable, but one of the main directions of the HSR system should be expanding passenger's demand by providing large capacity and high frequency service. Therefore, the operator needs to make long-term planned capital investment in rolling stocks and other facilities to flexibly increase operation frequency.

In the next chapter, we analyze the market condition in Texas. The discussion is based on how to utilize these competitive advantages we identified in this chapter, mainly from the viewpoints of customer and competitor in addition to that of the private company.

Chapter 6 Market Analysis for the Texas High Speed Rail

In Chapter 4, we identified the most important feature of the Texas HSR project: The operator has a freedom of action that enables the private company to pursue its most important goal, profitability, by re-investing in its infrastructure to fully utilize the HSR system's competitiveness, and consequently, by realizing stable growth of ridership. Then, in Chapter 5, we concluded that the primary advantages of the HSR system, as a part of a comprehensive transportation system, are its high speed, large capacity, and safe service. Especially, the Japanese Shinkansen technology can provide flexible operation frequency according to ridership growth, which can further enhance a customer's convenience by realizing high service availability.

In this chapter, we analyze the market condition in Texas to identify; the main target in the market; how the operator addresses the market in order to effectively attract customers; and how the private operator secures its competitive advantages with other modes in the market. These analyses should be conducted from the viewpoints of not only the HSR operator itself, but also potential customers and competitors. Whether the HSR could win the competition in the intercity passenger market depends on HSR's relative competitiveness, which could be enhanced or lessened by the strategic choice of the operator. Therefore, in this chapter, we conduct a market analysis to identify effective "strategic alternatives" [4] of the operator. This analysis is based on one of the common methodologies, "three Cs" analysis [5], as the second "ornament" of the CLIOS Process.

6.1 Overview of "The Strategic Triangle"

"The Strategic Triangle" is a framework for an analysis of the business environment, proposed by Ohmae in the early 1980's [5]. This analysis is for considering a company's competitive strategies in various markets from the viewpoints of three key players, Customer, Corporation and Competitor. These "strategic three Cs" are the main stakeholders who affect the competitiveness of the company based on their own interests. Ohmae claimed that it is crucial for the company under a competitive environment to identify and focus on "Key Factors for Success," which are defined as "key functional or operating areas that are decisive for the success of" its business [5]. Fig. 6-1 shows the basic concept of the 3Cs strategic triangle and relationships. This diagram shows that the Corporation should differentiate a value of its product/service from that of Competitors by utilizing the Corporation's own strengths and matching them with the Customer needs. Good competitive strategies are the ones that can enhance the "relative corporate strengths" over other competitors to improve targeted customers' satisfaction [5]. Ward et al. [115] compared the 3Cs framework with other popular ones, such as the five-force model of M. Porter [116] or SWOT analysis [117]. They argued that the Strategic Triangle analysis has an advantage of focusing more on a customer's viewpoint. The 3Cs analysis concept that the company should more concentrate on enhancing the customer's satisfaction is useful to simply analyze the market condition based on what targeted customers essentially need, Ward et al. claimed [115].

In Section 6.2.1, firstly we conduct the market analysis based on a customer's perspective. This analysis includes segmentation of the intercity passengers in Texas in terms of a customer's needs for each segmented category. By doing this analysis, we can identify which group of customers the Texas HSR should mainly focus on and what the customers really want and need from the HSR service. Then, we consider corporation-based strategies based on the discussion in the previous chapter about what the competitive edge of the HSR system is. In Section 6.2.2, we consider how and when the operation company can utilize the competitive advantages to gain stable ridership. Finally, we consider the market from the viewpoints of HSR's potential competitors, airline and automobile, to identify how the HSR can compete with other modes by attracting passengers from these existing competitors.

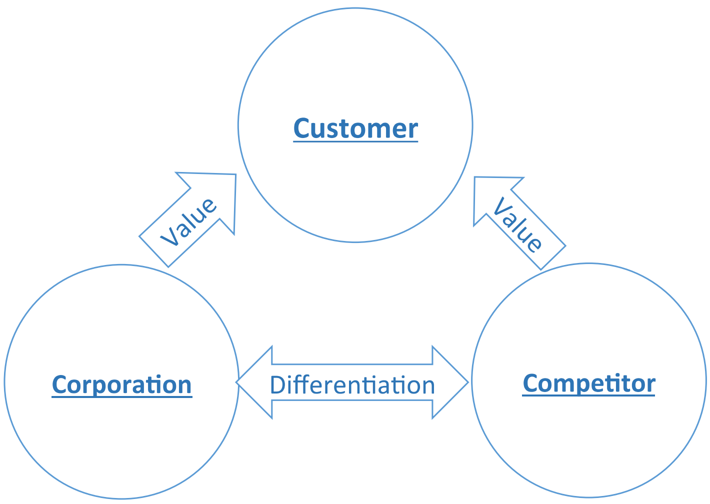


Fig.6- 1"The Strategic Triangle" of the 3Cs analysis

(Retrieved from [5])

6.2 "Three Cs" Analyses

6.2.1 Customer-Based Strategies

First, we conduct the market analysis from intercity passengers' standpoints in Texas. Ohmae mentioned that customers in a market have their own interests so they are not "homogeneous," and thus it is important for a corporation to "distinguish easily accessible customer groups from the hard-to-reach ones" by segmenting the market [5]. This concept is applicable to the market we analyze because transportation industries with a public nature will be used by a wide range of customers whose purposes of use, affordability and values are different. The following analyses are based on the procedure described in "The mind of the Strategist." [5]

・Market Segmentation by Objectives of Potential Customers

The market segmentation is conducted based on objectives of intercity passengers between the greater Houston and the North Texas areas. Texas Central Partners, the private operator, states that the passenger's purposes between these two regions will include private travel, such as visiting friends or family members, leisure and vacation travel, business travel, and student travel [88]. The Texas DOT claimed that the improved rail connections between the two megaregions could enhance the intercity business travel and also daily commuters to their work places [24][118]. Based on these trip purposes, we segment passengers into six categories as shown in Table 6-1. We evaluate the characteristics of these categories in terms of three variables: Price sensitivity, Value of Time, and Desirable Frequency.

Business travellers are divided into three categories: Intercity day trip, intercity overnight trip and daily commute. In general, these passengers have high value of time, and so they are willing to pay expensive fares to save their travel time. Intercity business passengers of both day trip and overnight trip are less sensitive to the ticket price, but the former prefer high frequency because they use HSR service twice (or more) in one day as a round trip, while the latter stay overnight at the destination and thus they do care somewhat less about the frequency. Both of them need refundable ticket and prefer to change the travel time at the last minute to flexibly adjust their schedule. Therefore, refundable and changeable regular tickets for business seat are suitable for these business users who need convenience of the service more than affordability. On the other hand, commuters who use HSR service for their daily commute have a high value of time, but they may be more sensitive to the ticket price because they use the service every day. They tend to desire higher frequency than other business travelers especially during rush hours. To capture their need, it might be effective to provide a commuter pass that allows them to reserve seats every weekday. The Texas HSR is a single link line that connects the two regions over 200 miles away, so the number of potential HSR commuters seems not so large, but if an affordable rail pass with high convenience of reservation system is introduced, it might induce the potential demand of interregional commuters.

HSR passengers for private use are divided into three categories: Luxury tourism and leisure, ordinary tourism and leisure, and student trip. Overall, the private passengers are not as sensitive to time saving as business travelers due to their relatively low value of time. The first category, luxury tourism and leisure passengers, represents the passengers who have low value of time but are not price sensitive because they are willing to pay expensive fares for high-class service. To attract them, it might be effective to introduce business class (or first-class, if any) ticket with high quality service such as meal. However, the majority of private passengers are considered to be price sensitive and have no need for flexible schedule change, so they will purchase an advanced ticket with a discount. Especially, college students who use HSR service for their access to the large cities from the intermediate station, which will be constructed in College Station (home of Texas A&M University) area [37], are much more price sensitive, therefore, the special discount ticket for students should be introduced to attract them.

・Market Segmentation by Customer Coverage

According to Ohmae, there is a tradeoff between marketing cost and coverage: if a company wants to broadly advertise its product/service in a specific market, it requires a large advertisement cost [5]. In the case of the Texas HSR project, the service is an interregional transportation between two megaregions, Houston and Dallas/Fort Worth areas. The coverage of the transportation service is geographically limited along with the rail line. The target segments are specific to the intercity travelers in the specific regions; therefore the company's marketing effort should be done "narrowly but deep" in the market [5]. By effective marketing and advertising effort, initial penetration speed and depth are enhanced, and the HSR operator could effectively expand ridership and eventually dominate the market.

Considering HSR's relatively expensive fare, the primary target should be an intercity business traveler who highly values high-speed, reliable and convenient service. In addition, it is also important to attract private passengers with low-value-of-time in order to realize stable and gradual growth for a long time. The combination of keeping price relatively low or providing discount ticket for these specific segments, and concentrated marketing effort to the target segments, could be a good strategy to penetrate into the market at an early stage. After the commencement of the service, the HSR operator should monitor passenger segments and check how many passengers in each category actually use the service to identify the effective strategy to further attract the new passengers from the market.

Table 6- 1 Market segmentation of potential passengers of the Texas HSR

	(Business) Day Trip	(Business) Overnight Trip	(Business) Daily Commute	(Private) Luxury Tourism & Leisure	(Private) Ordinary Tourism & Leisure	(Private) Student Trip
Price Sensitivity	Low	Low	High	Low	High	Very High
Value of Time	High	High	High	Low	Low	Low
Desirable Frequency	High	Low	Very High	Low	Low	Low
○: Prerequisite						
Refundable	○	○		○		
Change in Last Minute	○	○	○			
No Advance Purchase	○					
No Round Trip Requirement		○		○	○	○
★: Recommended Ticket Type						
Regular Ticket (Single Trip)		★				
Regular Ticket (Round Trip)	★					
Business Class Ticket	★	★		★		
Coach Class Ticket					★	
Advanced Discount Ticket					★	
Commuter Pass			★			
Student Discout Ticket						★

(Created by the Author)

6.2.2 Corporate-Based Strategies

The previous customer-based strategy is to find what the potential customers want and need. As the next step, we map out corporate-based strategies. The purpose of these strategies is to identify how the operator maximizes HSR's advantages in the Texas market. These advantages are called "key functions" that can differentiate the service of the HSR from other competitors. In this section, corporate-based strategies of the Texas HSR project are discussed based on the following two steps: "Selectivity and sequencing," and "Improving cost effectiveness." [5]

・"Selectivity and sequencing"

Ohmae claimed that it is not necessary for a corporation to have an advantage in all aspects of its performance. If a corporation has a specific "decisive edge" of important function at each phase, then the corporation is able to be superior to competitors. In case of the Texas HSR project, the competitive advantages over other modes are its high speed, large capacity, high frequency and good accessibility, which are discussed in Chapter 5. The operator should focus on utilizing these advantages not at once but one by one, by "sequencing the improvement of functional competence[s]." [5] Therefore, the company should consider its strategies based on the following strategic phases to secure ridership and modal share growth for a long run.

1. Penetration Phase

This phase is when the HSR operator tries to penetrate into the intercity passenger market, by developing the demand for the HSR service. The basic strength of total travel time saving due to the HSR's high speed and good accessibility should be highlighted to attract the primary target, business passengers. For example, limited sales price and strong promotion activity especially for the business users seems to be effective to attract early adopters. They will be the basis of long-term passenger growth because the word-of-mouth reputation of the new service is dispersed from these early adopters in the narrow market (This HSR market is geographically limited, as discussed in Section 6.2.1).

2. Demand Expansion Phase

This phase is when the HSR operator tries to attract passengers from a wide range of market segments, and thus ridership stably grows. By expanding seat supply, the operator should focus on utilizing its advantage in high capacity and frequency according to ridership growth (increase in operation cost – beyond scope in this thesis – should be taken into account, however). Price discrimination based on the passengers' need could be an effective strategy to control load factor and service availability of the main target business users if the capacity constraint could hinder ridership growth.

3. Market Domination Phase

This phase is when a market share of the HSR users is established to some extent after ridership growth saturates. In this phase, it is essential for the HSR operator to keep high retention rate of the customers by maintaining customer satisfaction and establishing brand image of the HSR. Keeping high standards of each trip attribute, such as total travel time, ticket price, convenience, reliability, comfort, safety, and so on, will be a key factor to seize and retain the customers in the long run. For example, mitigation of congestion around HSR stations by providing public transportation network could be a critical strategy to keep reliability of the HSR service high.

・“Improving cost effectiveness”

The other purpose of functional strategies is to improve cost effectiveness of the business [5]. The HSR operator should focus on attracting more and more passengers to realize “economies of density,” which is generally applicable to railroad industry [119]. By increasing “density of traffic” on the single-link HSR line, the fixed cost per passenger will be decreased, and consequently the ticket price would be more competitive with other lower-priced modes (automobile, inter-city bus service etc.). Especially, the cost structure of the Japanese HSR system has higher fixed cost (68-76% of total cost) and lower variable cost (24-32% of total cost) than that of airline industry. [106] Therefore, it could be a good strategy for the operator to increase operation frequency to enhance the utilization of infrastructure, while balancing the operation cost increase and the effect of “economies of density” on the HSR line.

6.2.3 Competitor-Based Strategies

In this section, we discuss how to enhance the HSR’s advantages from the viewpoint of competitors. Ohmae defined competitor-based strategies as “looking at possible sources of differentiation in functions,” between a corporation and other competitors [5]. As discussed several times, the Texas HSR project has to compete with other intercity transportation modes as a new entrant of the market. The main competitors are airline industries, intercity bus services and private automobile. Current modal share of the intercity passenger market between Houston and Dallas is almost dominated by automobiles using highway networks. The TCP's report claimed that there are over 14 million passengers traveling between the Greater Houston and the North Texas areas. Out of all of these trips, about 1 million passengers take flight annually, and right now, there is no train service between the two regions; therefore the market share is divided only between flight and highway, and around 95% is dedicated to car users, including intercity bus service [88]. We consider the strategies to attract passengers from other modes in this challenging market condition based on the following perspectives.

・"The power of an image"

Besides actual service quality and price competitiveness, an image of service has a significant role in a competitive market to attract customers [5]. Since there is no existing HSR service in Texas, no generally accepted image exists. People's tendency for mode choice does not change rapidly; thus it is essential to create a positive image of using HSR compared with road and flight before the commencement of the service. In terms of brand image, the private operator has tried to advertise a positive image of HSR technology by using the positive words, such as "innovative technology," "sophisticated," and "environmentally sound," to differentiate it from other conventional transportation modes [38]. Advertising effort by the company and good reputation from early adopters could be an effective source of initial ridership growth in the car-oriented society (these effects are mainly considered in the System Dynamics model in Chapter 8).

・"Capitalizing on profit and cost structure differences"

As discussed in the previous section, the HSR industry is a typical high-fixed and low-variable cost industry. If the ticket price is set too low considering the highway user's inexpensive cost (for example, the monetary cost calculated from the unit oil price and the average vehicle fuel consumption of a private car is about $35 from Houston to Dallas [120][121]. It does not include car maintenance fee, tax and other environmental cost, though), it will be difficult to make the HSR business profitable. Fierce price competition could be a threat to the HSR operator. Therefore, it is important for the HSR operator to take a strategy to provide transportation service with higher added values than other modes, and HSR operator should focus on attracting passengers who are willing to pay relatively high price for the travel time saving. Considering high economic growth in the regions [88], moderate price increase could be justified due to the increase in value of time, when the service quality is held high. The HSR operator has to avoid the fierce price war with automobiles, which have a totally different cost structure from the railroad industry.

6.2.4 Conclusion from Strategic Triangle Analyses

From the results of the previous 3Cs analyses, we identify important findings to guide the Texas HSR project toward success. First, to find customer-based strategies, we segment intercity passengers into several groups. We identify that business users would potentially be the main target of the HSR service, while various types of tickets should be provided to expand the market beyond business travellers and attract a wide range of customers based on their price sensitivity and needs. We also identify that effective promotion activity and capacity increase are the key factors to expand the market. The next corporate-based strategy we find is that the operator should change its managerial focus according to its market position in three phases. To utilize the strengths of the HSR system, accessibility to HSR stations from city centers should be considered seriously. In addition, the importance of frequency increase is noted under load factor management. Finally, based on the results of competitor-based strategies, we identify the importance of image marketing through advertising and reputation as a way of differentiating HSR service from other existing transportation modes. Another finding suggests that the operator should avoid a fierce price war with the main competitor, car users, by providing high quality service that could justify the relatively high fares. Based on these arguments, we summarize the following three "Key Factors for Success," or "strategic alternatives" (CLIOS Process terminology) in terms of three "strategic phases" [4][5]:

Key Factors for Success:

・Pricing strategy

Low price setting to attract a wide range of passengers is effective when the operator initially enters the market. Moderate price increases could be allowed during the demand expansion phase, and the operator should avoid getting deeply involved in a price war because of its cost structure. Price discrimination by providing various types of tickets could help HSR to attract a wide range of customers.

・Capacity management strategy

HSR's high capacity and frequency enable business users to flexibly change their travel schedule at the last minute. This convenience is an essential competitive advantage of the HSR service especially for business users. A high standard of service availability and convenience of frequent operation should be realized by load factor management during the demand expansion phase and the market domination phase to remain competitive.

・Accessibility management strategy

It is important for the HSR operator to position the HSR service as a part of a seamless comprehensive transportation system at the initial stage. From the viewpoint of the main target, business users, accessibility to HSR stations from business districts could be a criterion of whether they use HSR service or not, therefore HSR station locations and urban networks accessible to the stations are an important factor. During and after HSR ridership growth, it is highly likely that many passengers will use automobiles and cause serious congestion around HSR stations. Reducing the total travel time by providing public transportation networks is the key factor to make HSR successful. For this to occur, cooperation with public transportation agencies will be necessary.

In the next section, we investigate an actual case of the Taiwan HSR in terms of the three strategies we mentioned above to identify an effective example in the Texas case.

6.3 Comparison with the Taiwan HSR Case

In general, modal split of an intercity passenger market between two regions 200-400 miles away are determined by competition between rail, road and flight [101]. As we discussed in Section 6.2.3, automobiles and airlines dominate the current modal share of the 240-mile passenger market between Houston and Dallas. For the Texas HSR to compete with the existing modes, it is necessary for the HSR operator to attract a sufficient number of passengers from them. Now the question is, how is it possible for the HSR to attract customers as a new entrant in the interregional transportation market? In this section, we investigate a good historical reference for the Texas HSR, the Taiwan HSR project. In the following discussion, we find many similarities between the two HSR projects and therefore can identify several strategic lessons from the Taiwan HSR to apply to the Texas HSR case.

6.3.1 Overview of the Taiwan HSR

The Taiwan HSR started its operation in January 2007. The route is along a corridor in the western region between the Taipei and Kaohsiung areas, which are about 220 miles away. As Fig. 6-2 shows, these areas are the two most densely populated areas in Taiwan. 94% of the Taiwanese population (over 20 million) is distributed along the western corridor, which connects Taipei, Taichung and Kaohsiung [122] and thus the HSR connects the "backbone of the Taiwanese economy" [123]. The HSR line is a single-link system with 12 stations, including Nankang, Taipei, Banciao (Taipei area), Taichung (intermediate station) and Zuoying (Kaohsiung area), as shown in Fig. 6-3. There are several stopping patterns, including a direct train connecting the Taipei and Zuoying stations with an intermediate stop in Taichung. The travel time using the direct train from Taipei to Zuoying is 96 minutes.

The main objective in introducing the new HSR was to mitigate highway congestion on the western corridor, which had been a serious problem since the 1970s [104]. The project was funded by the Build-Operation-Transfer (BOT) scheme, which involves a private venture selected by the public sector to be built and operated for a certain concession period after which the infrastructure is transferred to the public sector [124] The concession period was originally set for 35 years, but it has been extended to 70 years to mitigate the financial burden of the private operation company, the Taiwan High Speed Rail Corporation (THSRC) [125].

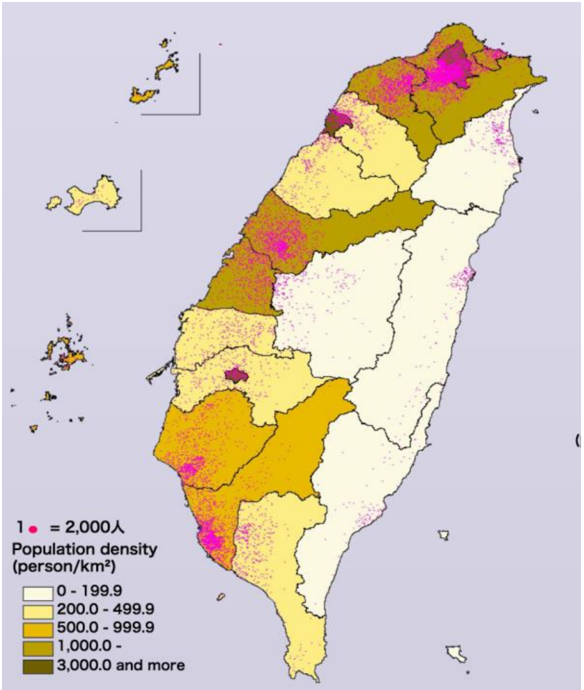


Fig.6- 2 Population distribution and density in Taiwan (2010)

(Retrieved from [126])

Fig.6- 3 HSR line alignment and 12 stations

(Retrieved from [122])

6.3.2 Similarities Between the Taiwan and Texas HSR

We compare the following aspects to identify the similarities between the Taiwan and Texas HSR systems with regard to technology, objectives and market conditions.

・Technology and alignment

The Taiwan HSR system was constructed based on the Japanese 700 series Shinkansen system. It uses dedicated tracks only for passenger HSR trains, which are designed based on the same "Crash Avoidance" principles [34] as are the other Japanese bullet trains. As we discussed in the previous sections, one of the crucial characteristics of the system is its flexibility in operation frequency in response to demand growth. Actually, operation frequency has dramatically increased according to ridership growth in the case of Taiwan (This is discussed in Section 6.3.4 in detail). Both HSRs connect two regions by a single-link line (the Taiwan HSR has 12 stations and the Texas HSR will have only three, though).

・Main objective & project goal

The main objective of these two HSR projects is to mitigate the traffic volume of existing highways and airlines that serve the regions as important economic arteries [127]. In both cases, the population in the regions connected by the HSR lines is projected to increase dramatically at the time of implementation. Thus, the high capacity and reliability HSR can provide would be a good solution to reduce the traffic burden of existing networks. On the other hand, both projects have the common goal of making the project profitable. Both HSRs are constructed, operated and maintained by private companies. In the Taiwan case, during the concession period, growing ridership and gaining sufficient revenue from passenger fare are the main objectives for the THSRC [104].

・Overall market condition

Both single-link lines connect two megaregions more than 200 miles away in about 90 minutes (the 215-mile Taipei-Kaohsiung corridor in Taiwan in 96 minutes, and the 240-mile Houston-Dallas corridor in Texas in 90 minutes). In both cases, direct train service has only one intermediate stop (the Taichung station in Taiwan, and the Shiro station in Texas) although there are train patterns that stop at all 12 stations on the Taiwan HSR. As discussed in Chapter 5, the distance and travel time on board are quite suitable for the HSR to compete with other modes, especially the airline industry. When the HSR was implemented in Taiwan, the middle-class could afford to pay for relatively expensive HSR tickets in terms of average GDP per capita (around US$16,000) [128]. The GDP per capita in the US is $49,844. In Texas, the figure is higher: $53,707 (2015) [129]. Historical data show that around 40% of the HSR passengers in Taiwan are business users, and around 60% are personal travelers [104]. This number is consistent with the USDOT's recommendation when estimating the portion of HSR users in the US (40.4% for business, and 59.6% for personal) [130]. Therefore, the market potential in Texas is almost the same as Taiwan at the time of HSR implementation. The main issue in both cases is competition with highway users. How to attract existing car users, including private cars and intercity buses, is the main consideration in these two markets. In the case of Taiwan, two thirds of the intercity passenger market between Taipei and Kaohsiung was dedicated to automobiles. After one year of the implementation of the Taiwan HSR, the proportion of car users decreased to 43%, while that of HSR users reached about 50%. In Texas, the existing market is nearly monopolized by highway users (estimated to be more than 90%, including intercity buses). Thus, it is important to divert passengers from the highway to HSR. Tables 5-2 and 5-3 summarize the comparisons and similarities between the two HSR projects. The market conditions are favorable while the airline industry is less competitive in the current market condition for both HSR cases. However, the market share of car users is high in both cases. Therefore, the transition from car users will also be a major factor to the success of the HSR operator in the proposed Texas HSR project.

We should note that there is a difference that could affect an HSR operation between the two cases. For example, car ownership rate in Taiwan is much lower than that in Texas. Huang et al. claimed that the introduction of Mass Rapid Transit system would suppress car ownership rate per households in Taipei, and households relying on public transportation have fewer cars [131]. As this result shows, people in Taiwan had already changed their tendency of mode choice when the HSR system was established in 2007. In Texas, on the other hand, the long-term trend of car dependence has increased [45]. This cultural difference is highly likely to make difference in ridership of both HSRs. When comparing the two HSR lines, it is necessary to consider how cultural difference affect ridership growth in Texas.

Table 6- 2 Comparison between Taiwan and Texas HSR project

	Taiwan High Speed Rail	Texas High Speed Rail
Technology	Based on the 700 series Shinkansen System (Rail, Signaling systems are based on TGV/ICE) Dedicated Tracks, Crash Avoidance	Based on the N700 series Shinkansen System Dedicated Tracks, Crash Avoidance
Targeted Market	Single link b/w two megaregions Middle class society affords to pay HSR ticket In terms of Value of Time	Single link b/w two megaregions Middle class society affords to pay HSR ticket In terms of Value of Time
Main Objective	Mitigation of HW Congestion Pursuing Profitability by the Private Company	Mitigation of HW Congestion Pursuing Profitability (Private Venture)
Main Competitor	Private car + Highway Bus 65% modal share (before HSR implementation)	Private car + Highway Bus Estimated over 90% modal share
Financial Scheme	Built Operate Transfer scheme (BOT) Private company conducts construction, operation, and maintenance (Concession period 70years)	Fully private funded Private company conducts construction, operation, and maintenance (No need to transfer the property)

Table 6- 3 Market similarities between Taiwan and Texas HSR

	Taiwan High Speed Rail	Texas High Speed Rail
Distance of terminus stations	Taipei area – Kaohsiung area, 215 miles Direct Train connects in 96minutes (intermediate stop in Taichung) *Trains stopping every 12station is also run	Houston area –Dallas FW area, 240 miles Direct Train connects in 90 minutes (intermediate stop in Brazos Valley)
Population around terminus stations	Taipei Area: 6.71 million Kaohsiung Area: 2.78 million (2010)	Houston area: 5.94 million Northern Texas area: 6.37 million (2010)
Targeted Market Demographic	Historical data shows, 40 % business trip 60% personal (leisure, visiting friends etc.)	40.4% business trip 59.6% personal (USDOT's recommendation for US HSRs)
Market Share before (and after) the HSR implementation	Car users, 66% (→ 43% after the HSR) Airline, 25% (→ 5% after the HSR) Conventional Rail, 9% (→ 2% after the HSR) HSR, 0% (→ 50% after the inauguration)	Car users, 93 % Airline, 7 % (Estimation)

(Created by the author based on references [21][88][104][122][123][126][130])

6.3.3 Overall Trend of Ridership and Operation Frequency

In this section, we investigate the overall trend of HSR ridership growth in Taiwan to identify the characteristics of HSR market development. We can obtain monthly data (2007 to 2016) of total HSR ridership, load factor of all types of trains, and passenger traffic amount of each station (in and out) from the public documents of the Taiwan Ministry of Transportation and Communications (MOTC) [132]. Fig. 6-4 shows the development of all ridership, average load factor and seat capacity, which is calculated from ridership and load factor. As an overall trend, ridership (blue line) has steadily increased since its commencement of service in 2007. Seat capacity (green line) drastically increased during the initial two years even though load factor (red line) dropped. Since 2009 seat capacity has gently increased, and load factor has also gradually increased, reaching above 60% around 2015. From average passenger number data of each station (in and out), we estimate[2] that on average 19.1% of HSR passengers move from the Taipei to Kaohsiung areas using direct trains that stop only in the Nangang, Taipei, Banqiao (Taipei area), Taichung (intermediate stop) and Zuoying (Kaohsiung area) stations. We could estimate operation frequency of the direct train from the current timetable of all trains [133], assuming the proportion of the direct train is constant at 21.5% (These data will be used in the System Dynamics model training in Chapter 8).

Although overall ridership is stably increasing, the growth rate has not been increasing as much as operation frequency during the initial three years. Li et al. claimed that there is a certain time lag (2-3 years) between ridership growth and service improvement, such as frequency increase. This phenomenon is called the “demand adaptation” to new transportation service [134]. Cheng mentioned that ridership is below the initial expectation because business trips between Taipei and Kaohsiung have not increased as much as the operator had expected [104]. The private operator has tried to boost demand by introducing several strategies related to pricing, capacity management and accessibility to HSR stations, which are discussed in the next section.

[2] From passenger number data in/out each station, we conduct Iterative Proportional Fitting [119][135] to create origin-destination matrix for 12 stations.

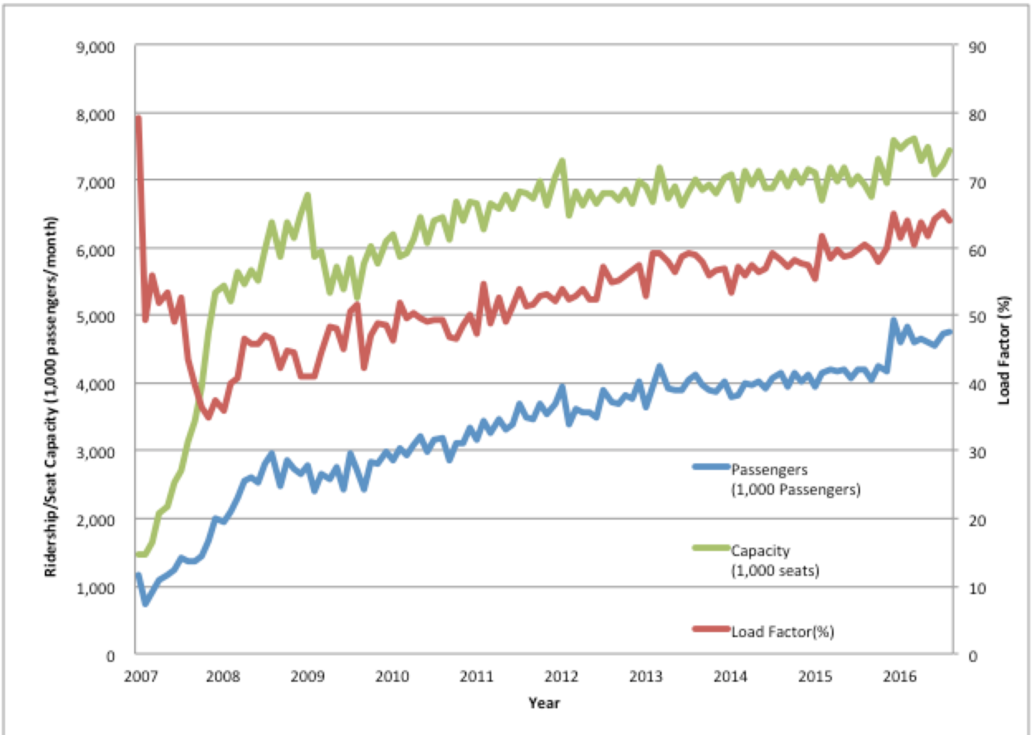


Fig.6- 4 Historical data of the Taiwan HSR

(monthly ridership, seat capacity, average load factor)

(Data Source: Taiwan Ministry of Transportation and Communications (MOTC) [132])

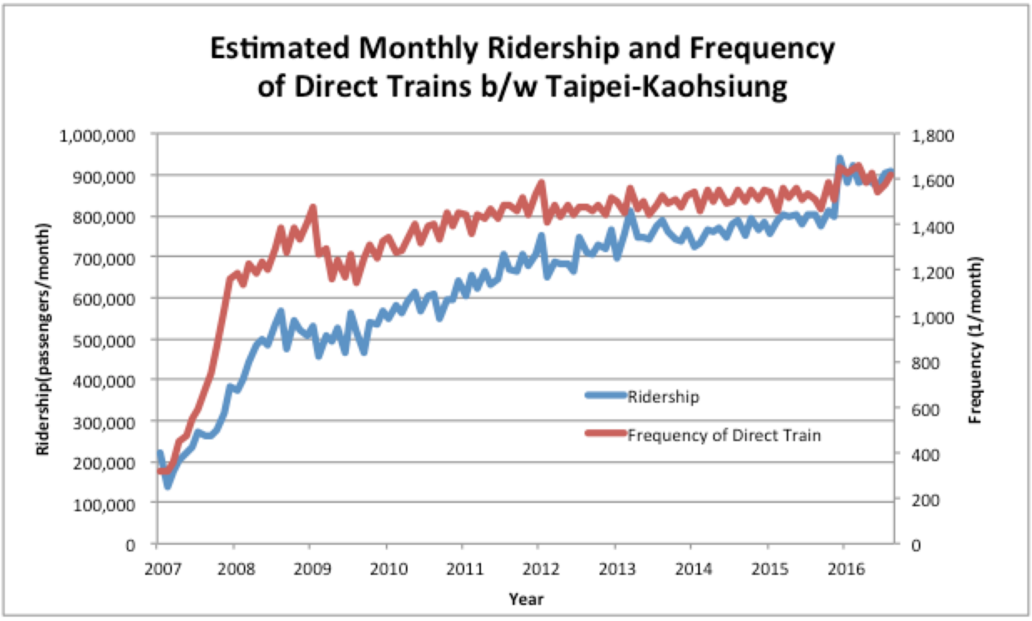


Fig.6- 5 Estimated ridership, frequency of direct train between Taipei-Kaohsiung areas

(Nangang, Taipei, Banqiao stations -Zuoying station)

(Data Source: Taiwan Ministry of Transportation and Communications (MOTC) [132])

6.3.4 Lessons from Taiwan HSR Case

As a result of "the Strategic Triangle" market analysis in Section 6.2, we identify that there are three main strategies the Texas HSR operator could combine to attract passengers and compete with other modes: Pricing, capacity management, and accessibility management. Considering the actual case in Taiwan, which resembles the case in Texas especially in terms of market condition, we can promote a better understanding of competitive strategies that the operator should utilize in each phase. The following discussions are conducted based on three strategic viewpoints.

・Pricing strategy

The HSR operator in Taiwan introduced several discounts to attract passengers. For example, for three weeks just after the commencement of service in January 2007, regular ticket price was discounted by 50%. The purpose of this strategy was to attract initial adopters and to increase repeat users during the penetration phase, but ridership decreased dramatically after the discount campaign was over; thus it was uncertain whether this strategy was effective or not [123]. Ridership growth was below the initial expectation of the operator during the first year. Then, starting in March 2008, the operator introduced 20% discounts for all weekday tickets (except Friday) to boost potential demand [104]. Cheng claimed that this discount strategy boosted ridership to some extent, but the operator should "address various market-segment[s]" by flexibly introducing several types of tickets such as commuting tickets [104]. Cheng also mentioned the importance of relaxation of governmental price regulation to allow the operator to set price more flexibly [104]. Pricing strategy is directly intervened by government policy in Taiwan because the project is based on the concession contract between the operator and the public sector.

In Texas, on the other hand, the project is financially free from the public sector, and thus the operator has the freedom of setting pricing strategies to pursue profit maximization (Government intervention on pricing is unlikely to happen because the project is fully private funded). Considering the basic cost structure of the HSR system (as discussed in the previous section), the Texas HSR operator should avoid decreasing ticket price indiscriminately. Therefore, it should focus on reinforcing HSR's advantages to justify the price difference between highway users and attract passengers who place a relatively high value on their time.

・Capacity Management

In Taiwan, operation frequency seems to intentionally increase in the initial few years despite sluggish load factor, as shown in Fig. 6-4. The initial frequency of the train was 19 two-way trains per day in January 2007. However, this number increased drastically in the initial two years, reaching more than 65 trains per weekday in July 2008 [104]. A University of Pennsylvania report [128] pointed that HSR ridership has grown according to its frequency. The report mentioned that the specific "break-even point" was around "60% load factor at a frequency of [44] trains per day [per each direction]," according to an operating manager of the company. We can gain the insight from Fig. 6-4 that average load factor seems to be managed below 70% by increasing frequency and supplying seat capacity. We can speculate that the operator has a target load factor around 60-65% to secure high service availability and convenience for customers.

As we discussed in the previous chapter, high frequency and capacity enables customers who highly value their time to flexibly make last-minute reservations. High service availability could be a competitive advantage of the Texas HSR, and so the operator should increase frequency according to ridership growth and control the load factor below the desired level (the operation cost increase is not considered in this discussion, though). This strategy could induce further ridership growth by providing convenient service to the customers.

・Accessibility to terminal stations

The importance of accessibility management is pointed out in the Taiwan HSR case. Cheng compared the change in modal share of HSR compared with other modes (air, intercity bus, private car, conventional railway) in terms of accessibility from each station to each city center. Cheng concluded that the three stations built in the city center, Taipei, Banciao and Zuoying, can attract passengers well, while the stations far from the downtown area, such as Tainan, which is 30-40 minutes away from downtown, have difficulty competing with other modes, especially the automobile [104]. Ni mentioned that "Urban [p]lanning and [l]and [d]evelopment with help from [l]ocal [g]overnment" is needed to enhance good accessibility of HSR stations from business districts and city centers [122].

A seamless transportation network including efficient public transit is necessary to manage accessibility to the HSR stations in Texas as well. The HSR system has to compete mainly with automobile, which provides convenient door-to-door service, and so implementation of the public transit system in Texas could be a crucial strategy for the HSR operator.

6.4 Conclusion from Qualitative Analyses

In Chapters 5 and 6, "the identification and design" of the three strategic alternatives are conducted by doing a comparative study of HSR system and market analysis by the "strategic triangle" framework, as two "ornaments" of the CLIOS Process [4][5]. We also learn important lessons from the actual Taiwan HSR case, which resembles the case in Texas in terms of market characteristics. Through these qualitative analyses, we draw the following important strategic suggestions:

How can the operator enhance ridership of HSR and secure profitability?

・Pricing strategy

Low price setting is potentially effective to attract new HSR adopters as the operator newly enters the market, but the operator should avoid getting deeply involved in a price war with other modes of transportation.

・Capacity management

HSR's high frequency and capacity enable customers to flexibly use the HSR service in last-minute situation. This is a core value that the HSR provides for customers who highly value their time. Thus, a high standard of service availability realized by load factor management and high operation frequency could be an important advantage of the HSR system.

・Accessibility to stations

Considering the high rate of car ownership in Texas, it is predicted that many passengers will use private vehicles to access the HSR stations, causing serious congestion. Reducing the total travel time of HSR users by introducing accessible public transportation is the key factor for success. There is a need for public transportation as a "feeder" of HSR system to make a seamless transportation system.

The other insights gained from the Taiwan HSR case are that these three key strategies should be implemented in particular ways in each phase after the commencement of service.

When should the operator implement each strategy?

・Penetration Phase:

This phase is when the demand for the HSR service is developed and the HSR penetrates into the intercity passenger market. Pricing strategy and marketing effort, such as limited sales price for the first few months and strong promotional activity, could be good strategies to attract an early adopters.

・Demand Expansion Phase:

This phase is when ridership stably grows in the market and the HSR adopters are expanding to a wide range of passengers. To attract more and more passengers, it is necessary to increase available seat capacity and frequency of train operation. Moderate price increases could possibly be allowed in exchange for the convenience of a high frequency operation.

・Market Domination Phase:

This phase is when the ridership growth saturates and a certain proportion of intercity passengers are dedicated HSR users. In this phase, it is important for the operator to establish and maintain the service quality, which consists of total travel time, ticket price, convenience and other attributes such as comfort, safety, brand image and so on. Keeping a high customer retention rate based on reputation is another key factor for success.

As the next step, we need to conduct quantitative analysis considering these "strategic alternatives" derived from the previous qualitative analyses [4]. Time-series analysis of ridership growth is necessary to identify the timely strategies the HSR operator should take in each of the three phases. However, the HSR system has a complex structure, and thus the causal relations of each component should be treated in a holistic way to capture the dynamic behavior of the system. Therefore, the System Dynamics (SD) approach is introduced as the final "ornament" of the CLIOS Process in the next Chapter.

Chapter 7 Application of System Dynamics Approach

In this chapter, the basic concept of the System Dynamics (SD) is introduced. The SD approach is used as the third "ornament" of the CLIOS Process [4] to conduct a quantitative evaluation of the three "strategic alternatives" -pricing, capacity management and accessibility management- discussed in the previous chapter. This method is suitable to predict overall system behavior of the Texas HSR in terms of ridership growth after its implementation. The purpose of using the SD approach is to identify the most effective way of "how" and "when" the operator can improve system performance (e.g. enhance ridership growth) by influencing certain aspects of the complex HSR system. In this way, the SD can complement the other qualitative analysis in the CLIOS Process, as discussed in Chapters 4, 5 and 6.

7.1 Summary of the System Dynamics Approach

Originally, System Dynamics was called "industrial dynamics" a concept established by Forrester and described as "the application of feedback concepts to social systems" [136]. The method has been developed in a wide range of fields because it can provide people with a "holistic, broad, long-term, dynamic view" for the complex behavior of various social systems [137]. Since people's viewpoint is too short-sighted, and it is difficult for them to mentally grasp the full complexity of social systems, computer simulation plays an important role to help them understand how to make decision to improve the performance of a complex and dynamic system. The SD approach consists of two central concepts: Feedback loops in Causal Loop Diagrams, and Stock and Flow structure [137].

A Causal Loop Diagram (CLD) is a method to represent the complex causal relationships between components in the system, including several feedback structures. Each component in CLD is connected by arrows ("causal links") having either positive (+) or negative (-) polarities. Positive polarity (+) means the increase/decrease in one variable similarly causes the increase/decrease in the other variable that is connected to the original one by a positive link. On the contrary, negative polarity (-) means that an increase/decrease in one variable causes the decrease/increase in the other variable, which is connected to the original one by a negative link. The combination of these multiple causal links forms two types of feedback loops: a reinforcing feedback loop, and a balancing feedback loop. The former is represented by a round arrow with an "R," and the latter is represented by a round arrow with a "B" to clearly show whether the feedback loop has a positive or negative feedback effect on the variables the loop includes. The simple example of "the dynamics of chicken population" CLD was shown in Fig. 7-1 [137]. In this CLD, a reinforcing loop shows that when the number of chickens increases, then the number of eggs increases and consequently, the number of chickens further increases. On the other hand, a balancing loop shows that the increase in chickens leads to the increase of road crossings, and in turn, the number of chickens decreases due to death by a traffic accident. The dynamics of the chicken population are determined by the balance of these two feedback loops. In this thesis, ridership of the Texas HSR system, which has a further complex structure of causal relationships, is analyzed using the CLD method to identify several feedback structures in Chapter 8.

As a next step, the concept of Stock and Flow is introduced to represent the accumulation and inflow/outflow of some variables in the system. Fig. 7-2 shows the basic example of a Stock/Flow diagram of population. In this model, the number of population is Stock, and Birth and Death Rate are the Inflow/Outflow of the system. The mathematical meaning of Stock is an integral of its Flows (Inflow and Outflow) during a certain time horizon. The amount of Stock at the time t can be calculated using the following equation:

$$Stock\ (t) = \int_{t_0}^{t} (Net\ Change\ in\ Stock) ds\ +\ Stock(t_0) = \int_{t_0}^{t} (Inflow(s) - Outflow(s))\ ds\ +\ Stock(t_0)$$

Important characteristics of Stock are that it can represent "inertia and memory" of the state of the system, "delay" resulted from time lags between output and input, and "disequilibrium dynamics" of the state of the system [137]. Implementing the concept of Stock/Flow enables the SD model to capture the dynamic behavior of variables with a certain time delay in a time series manner. These concepts are the basis of creating a conceptual and numerical model in the next chapter.

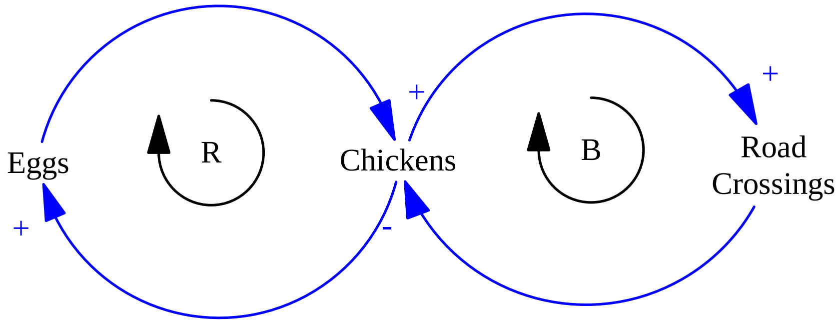


Fig.7- 1 Causal loop diagram of chicken population

(Retrieved from [137])

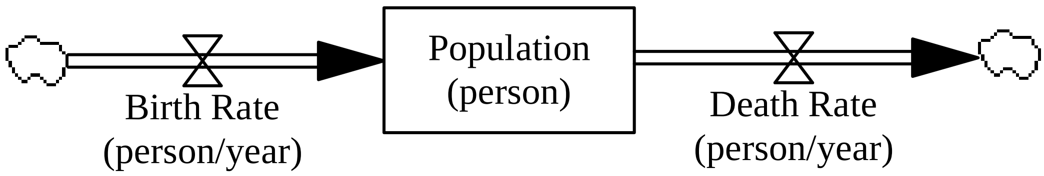


Fig.7- 2 Stock/Flow diagram of population dynamics

(Retrieved from [137])

7.2 Applicability of SD to transportation analysis

The SD approach, which captures a dynamic behavior of a complex system, is applicable to many research fields. One of these fields is the transportation area, which is characterized by its complex sociotechnical system [138]. Since a transportation system inherently includes various stakeholders and physical complexity, it is difficult to improve the entire system performance by influencing only one aspect of the system. Therefore, a holistic approach is necessary, and the SD approach is one of the suitable methodologies to analyze a transportation system quantitatively. Some advantages of the SD approach applied to the transportation field are identified by Abbas & Bell as follows [138]:

・“Dynamic interactions between supply and demand” of transportation system can be analyzed;

・“Nonlinearities and time delays” of each component’s variance can be simulated dynamically;

・Conceptualization based on the “modeler’s mental model” are transparently structured;

・Various “policy options” can be tested by providing flexible design and analysis of the model;

・“The short-term and long-term behavior” can be captured, so that it is possible to provide “timely adjustments” for the system;

・Controlling structures in the transportation models are identified, which enables policymakers to improve system performance. (Retrieved from [138])

Based on these advantages, numerous researchers used the SD approach in the transportation field. Shepherd quoted various studies in his review of the SD models applied in the transportation area [139]. In the summary, he introduced several basic models including the Bass Diffusion model, which is applicable to the diffusion mechanism of the new technology in the market (this model is used in this research, as described in the next chapter). Some other researchers focus on the effect of a new policy on people’s mode choice. Acharya claimed that an early implementation of a rapid transit system is crucial to secure the stable urban mobility from the results of the SD modeling, which simulates the modal share of public transportation in rapidly expanding cities [140]. Han et al. analyzed a change in modal split of intercity transportation by modeling fuel unit cost, capacity, network length and other variables [142]. They compared time variation of modal split in terms of three different policy scenarios. Doi defined the safety, availability and profitability of an HSR system as “ilities,” and evaluate quantitatively “ilities” of the Northeast Corridor in the US and the Tokaido corridor in Japan by applying the SD approach to analyze ridership, operating cost and unit price [142]. He used the Cobb-Douglas function to estimate ridership, using the initial value of the first year in his simulation as reference value, and thus he did not consider the penetration process of the new mode in the market.

As the reader can see, there are many researchers applying the SD approach to the transportation field, especially in the analysis and prediction of policy effect accompanied with certain time lags between implementation and its results. In this research, the SD approach is used as a part of the CLIOS Process to conduct quantitative analysis in over time from the holistic viewpoint of the complex HSR system in Texas.

Chapter 8: System Dynamics Modeling and Causal Loop Diagrams

The purpose of this chapter is to investigate the time-series variation of several key variables, such as ridership, load factor and revenue, of the Texas HSR by using the SD model. In the previous chapters, we identified ridership growth was affected by the impacts of three strategic alternatives: pricing strategy, capacity management, and accessibility management. Estimating the tendency of ridership growth (or decline) during a certain time horizon is crucial for the private operation company, TCP, to make its own decision-making in the competitive market of inter-city transportation. As a first step, we define the problems to set the appropriate boundary for the SD model. When we consider the model formulation, it is necessary to think about who needs this model and for what reasons. The SD model in this chapter is basically created for the private operator of the Texas HSR, which is explained in Section 8.1.

As the second step, several Causal Loop Diagrams (CLDs) based on the Bass Diffusion Model and three strategic alternatives will be presented. In the CLDs, we identify several feedback structures that have an impact on the demand for the HSR service. Then, each component CLD is integrated to form one integrated CLD, including ridership, price, travel time, load factor and other variables. Through this process, several new feedback loops emerge in one diagram. This is described in Sections 8.2 and 8.3.

Next, we convert this CLD into a numerical SD model to conduct quantitative evaluation of the estimated ridership and other factors. To identify several input parameters, first we apply the SD model to the Taiwan HSR case, and fit the simulation results to the historical data of ridership development in Taiwan. This model training is based on the assumption that the SD model, which represents the behavior of the Taiwan HSR case, is applicable to the Texas HSR as well. The purpose of this process is to create the SD model that captures the behavioral characteristics of the HSR system both in Taiwan and in the assumed Texas case. After this training, we can find reasonable numerical values for the input parameters. These processes will be explained in Sections 8.4 and 8.5.

Finally, we conduct sensitivity analyses for the Texas HSR market. As the first step, we conduct sensitivity analyses for the input parameters as estimated using Taiwan HSR data. This sensitivity analysis confirms the robustness of the numerical model behavior in terms of uncertainties in the estimated values of these input parameters. Then, we conduct sensitivity analysis in terms of three strategies: pricing, capacity management and accessibility management. We should note that each numerical value we obtain from the simulation results might not be accurate because the input parameters are estimated based on the data in Taiwan. However, it is useful to try to predict the system behavior and to discuss how overall ridership and revenue growth trends are affected by the three strategies from the viewpoint of the operator. This is discussed in Sections 8.6 and 8.7 [138].

8.1 Definition of Problem

For the first step of System Dynamics modeling, it is necessary to articulate the boundary of the system based on what types of information we need and for whom. The Texas HSR system is a typical CLIOS System, as defined in Chapter 4. Various stakeholders have an influence on the system and the system has a large impact on their interests. Therefore, we should differentiate between the inside and outside of the system by defining a clear boundary. The boundary will define which variables are exogenous and which are endogenous. While exogenous variables are not affected by the other variables in the model, endogenous variables are changed, controlled and influenced by others. Therefore, all of the feedback loops consist only of endogenous factors.

In this research, the purpose of using a SD model is to clarify the important factors for success for the private operator, TCP, from the viewpoint of how to steadily increase the ridership and secure the operating revenue. Thus, the boundary of the SD model will differentiate between the inside and outside of the system from the standpoint of its operator, and thus, the components inside the system boundary are what the private entity could control directly or indirectly. This model can help the operator understand competitive strategies in comparison with other transportation modes in Texas.

As mentioned several times in the previous chapters, profitability is the most important indicator for the project because the private sector venture has total responsibility for construction, operation, and maintenance of the HSR system. The profitability of the transportation system is determined as a balance of revenue and cost. As a first step of estimating the project's profitability, this research focuses on the company's strategy to obtain sufficient revenue by realizing stable ridership growth. While structuring the SD model, we focus on the balance of demand and supply of the service (e.g. how to adjust the seat price to accommodate riders' needs or increase supply of the seats). The cost estimation is considered beyond the scope of this research.

8.2 System Conceptualization (Causal Loop Diagrams)

In this section, we will show the basic structure of HSR ridership growth by creating Causal Loop Diagrams (CLDs) as a step of the conceptualization [137] [138]. Our SD model is based on the Bass Diffusion Model, which is applicable to the diffusion process of innovative products. With this basic structure, three CLD subparts, corresponding to price, capacity and travel time, are added to formulate the integrated CLD of the Texas HSR system. By creating the integrated CLD, several feedback loops emerged in the model

8.2.1 The Bass Diffusion Model

In general, a passenger's preference of mode choice does not change easily after the implementation of the new HSR line. Even after the income level reaches the sufficient level to afford an expensive ticket, it may take at least a few months for people to recognize the service quality and to actually adopt it. Li et al. called this tendency the process of "Demand Adaptation to New P[ublic]T[ransportation] Services." [134] Therefore, we need to structure the SD model, which reflects this adaptation process during the demand development phase for the Texas HSR.

With regard to this point, we assume that the Bass Diffusion Model could be applied to the demand forecast of a newly introduced HSR in an inter-city passenger market. The Bass Diffusion Model is one of the most famous models "for new product growth and is widely used in marketing, strategy, management of technology." [137] The Bass Diffusion Model is based on three factors: potential adopters primarily notice the external information of innovative products or services, they are affected by advertisement and word of mouth of actual adopters, and finally they actually adopt the new products or services. Shepherd pointed out that several studies applied the Bass Diffusion Model to the transportation areas when considering a new technology development and its diffusion in the transportation market [139]. Thus, we assume that the Bass Diffusion Model is applicable to the demand development phase of the HSR system.

The basic model structure of the Bass Diffusion Model in this research is shown in Fig. 8-1. To consider the HSR modal share in the market of intercity passenger travel, we divide the passengers into the following three categories: Passengers Not Willing to Adopt HSR, Potential HSR Adopters, and HSR Adopters. Passengers Not Willing to Adopt HSR are the intercity passengers who are not willing to pay for expensive HSR tickets to move between two regions. They become interested in using HSR services when they think it is reasonable to pay the ticket price to save travel time (Becoming Interested [person/month]). Potential HSR Adopters are the intercity passengers who would be willing to adopt the HSR service but have not yet used it. If they were exposed to the external information of a good reputation or advertisement, they would adopt HSR service at the pace of Adoption Rate [person/month]. HSR Adopters are the intercity passengers who actually use the HSR service, some of whom stop using the service. In this way, the total intercity passenger market is the sum of these three categories. The size of this market is expanding every month according to the Net Passenger Increase Rate, as shown in Fig. 8-2. In this model, Willingness to Adopt is defined as a probability of preferring HSR as a means of transportation. Primarily, this is a function of Total Travel Time and Average Seat Price referring their own Value of Time (VOT), which means how much individuals are willing to pay to save unit time. The unit of VOT is, therefore, [$/hour] in this model. In the numerical SD model, the VOT will be given by the reference table that represents the distribution of the intercity passengers' VOT. Churn Rate is also affected by Willingness to Adopt in terms of ticket price and time saving.

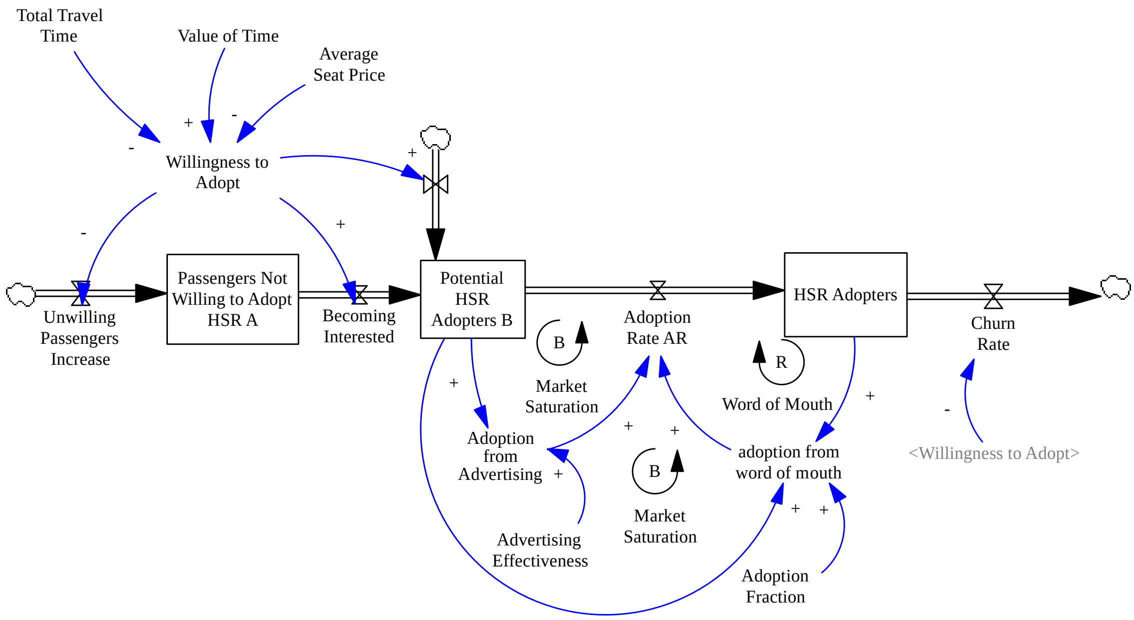


Fig.8- 1 The basic CLD of the HSR adoption based on the Bass Diffusion Model

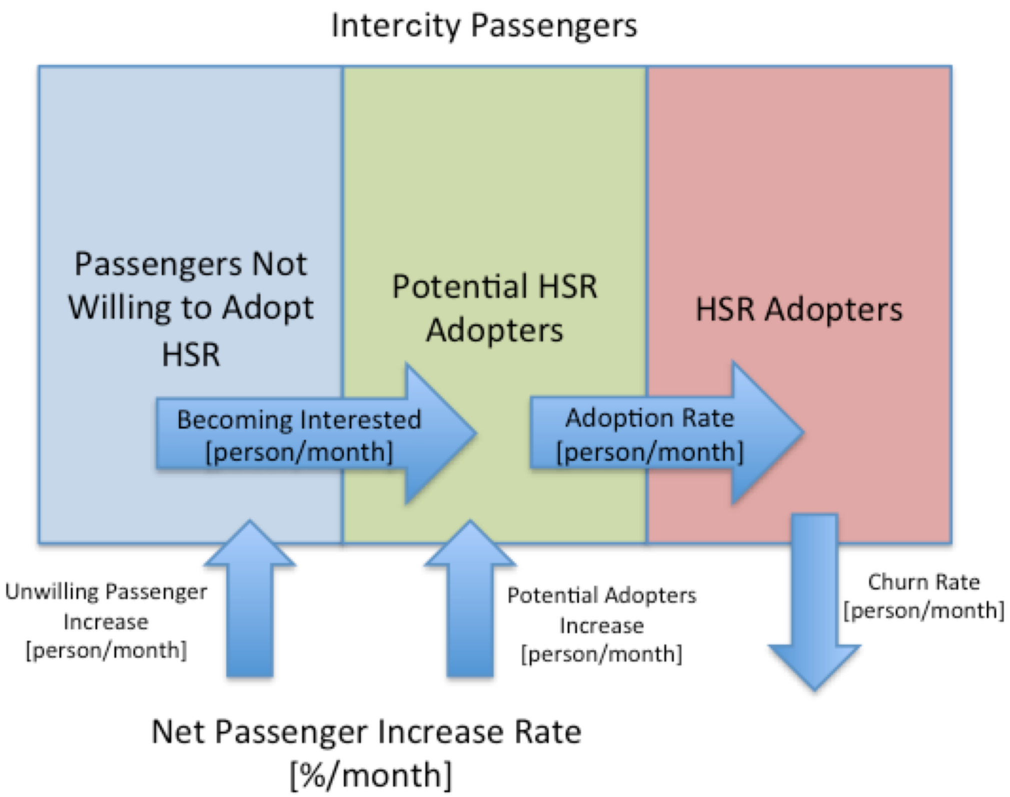


Fig.8- 2 Three categories of intercity passengers

The Adoption Rate of Potential HSR adopters who start using the HSR service is the sum of the Adoption from Advertising and Word of Mouth. Some fraction of Potential Adopters are affected by advertisements and consequently adopt the HSR, so Adoption from Advertising is a function of Advertising Effectiveness and the number of Potential Adopters. The Adoption from Word of Mouth is determined by the product of the probability of contacts with the actual adopters, which is calculated as HSR Adopters divided by Total Population in the regions, the number of Potential Adopters, and the constant value representing persuasiveness of the external information, Adoption Fraction [137]. There are two feedback loops that define the main characteristics of the Bass Diffusion Model. They are as follows:

・**Balancing Loop of Market Saturation**

The increased adoption from advertising and word of mouth decreases the stock of Potential HSR Adopters, who are the basis of further adoption. The company depleted the potential adopters, and therefore, the HSR adoption rate slows down due to market saturation.

・**Reinforcing Loop of Word of Mouth**

An increase in the number of HSR adopters who are satisfied with the service contributes to increase adoption from word of mouth. These new HSR adopters further contribute to new adoption of Potential Adopters; therefore it further augments the number of HSR Adopters.

8.2.2 Pricing Subpart

One of the most influential variables on the ridership growth and revenue is the ticket price of the HSR. In this Pricing subpart, the Average Seat Price depends on the Indicated Seat Price, which is directly affected by the balance of supply and demand of the service. With a certain time delay, Average Seat Price is converging to the Indicated Seat Price. Load Factor (LF) is the ratio of seat supply and the actual HSR ridership, and thus this is an indicator of the balance of supply and demand, directly having impact on the Indicated Seat Price (LF is calculated as the number of the HSR Adopters divided by the amount of Available Seats). The operating Revenue is the product of Average Seat Price and the number of HSR Adopters. These causal relationships are shown in Fig. 8-3.

Even though the fixed cost of operations and maintenance, and variable costs of increasing train frequency should have an impact on the ticket price, our approach assumes that the price is determined by the balance of demand and supply. As noted earlier, these cost estimations are beyond the scope of this research. Even so, average seat price is the important indicator of the system performance in this model.

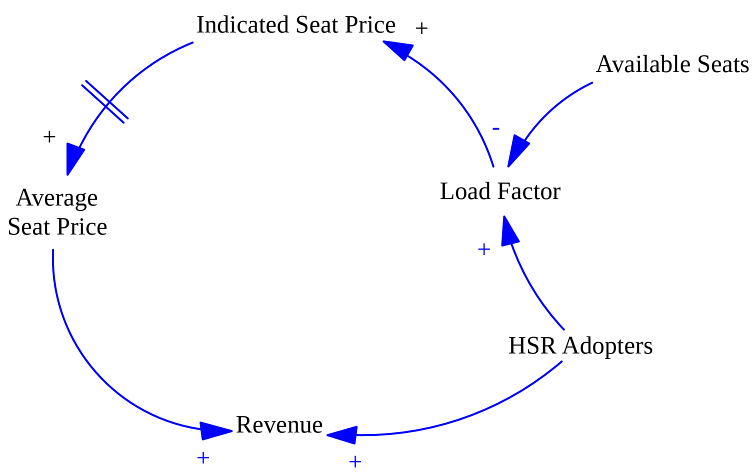


Fig.8- 3 CLD in Pricing subpart

8.2.3 Capacity Subpart

As discussed in the previous section, the number of Available Seats is the supply side of the HSR operation. This is determined by the train Frequency and Capacity per Train. In the Texas HSR system, the capacity per train is fixed at 400 [seats/train] and does not change permanently; therefore the Frequency is the only variable that directly affects the amount of available seats. In the model, the average LF of the train is converging to the Desired LF level, which is determined by the HSR operator. When the actual LF exceeds the desired level of LF, more seats are supplied to suppress the LF to the desired level by increasing train frequency to the Desired Frequency level. We call this process Load Factor Management of the operation company, and this formulates the balancing loop of the Load Factor Management, as shown in Fig. 8-4. The operation company adjusts the LF to the desired level by increasing frequency because it is convenient for the HSR adopters to enjoy the high frequency service. Convenience due to the frequent operation is a key factor to keep high retention rate of the customers. Also, the company should think about the service availability. As discussed in Chapter 5, the availability, which shows people can get tickets whenever they like, is the key advantage of the HSR. If the average LF is too high, the possibility that the passenger can find their seats at their preferred time gets lower. Therefore, the operator should take care of the LF, to keep Service Availability high and to help secure ridership growth.

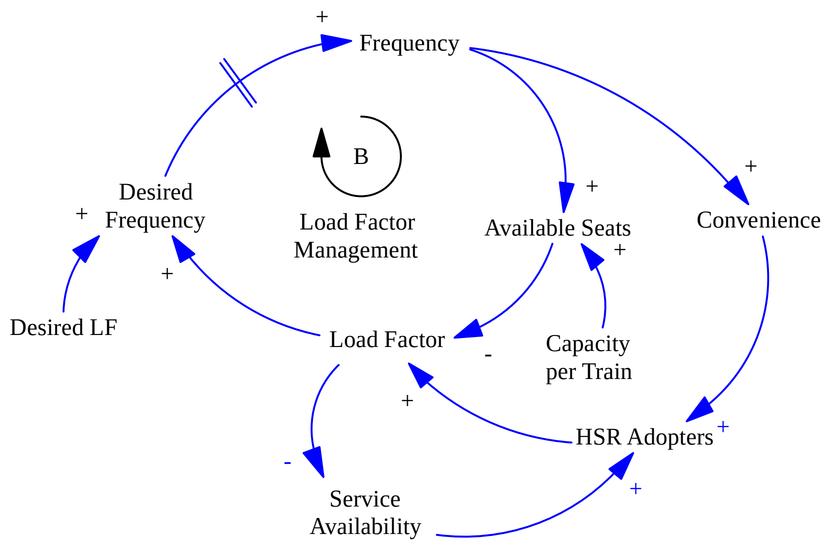


Fig.8- 4 CLD in Capacity subpart

8.2.4 Total Travel Time Subpart

For the HSR operator, it is essential to consider not only the Time on Board (90 minutes, in case of the Texas HSR) but also the Total Travel Time of intercity passengers to move from origin to destination. For the HSR adopters, the Total Travel Time includes Average Wait Time at the station, which is a function of Frequency, and the Average Access Time to Station of HSR in both cities. In this model, we assume that the HSR Adopters access stations by either Public Transportation or car. The portion of the public transportation users (Public Transportation Fraction) are affected by the utility of the public mass transit system compared with that of car facilities, such as road capacity and parking space. The access time of passengers who use public transit is predictable, while the passengers who use cars may be delayed by the Road Congestion and may have to wait for the Parking around stations. Average

Access Time to HSR station is the access time proportionately calculated from the access time of car users and public transportation users. This value is affected by Public Transportation Fraction, as shown in Fig. 8-5.

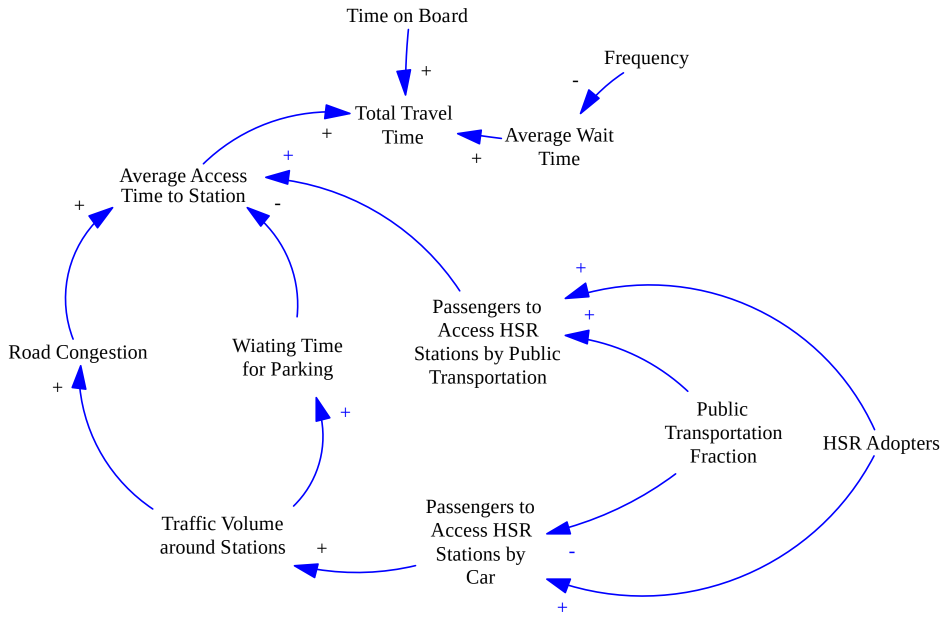


Fig.8- 5 CLD in Total Travel Time subpart

8.2.5 Integrated SD Model

Fig 8-6 shows the overall CLD of the Texas HSR system integrating Fig.8-1, Fig.8-3, Fig. 8-4, and Fig.8-5 in one diagram. To clearly show the causal relationships of the variables, some variables are simplified or eliminated from this diagram (for example, the number of Passengers to Access the HSR Stations by Public Transportation in Fig. 8-5 is eliminated. Public Transportation Fraction simply represents it, instead). We can identify several additional feedback loops in the integrated model. All feedback loops included in the diagram are as follows:

Balancing feedback loops

・**Price Increase**

The increasing number of the HSR Adopters increases the LF, and therefore, the Indicated Price goes up. Average Seat Price is increased with certain delay time to the indicated value, and it lowers the Willingness to Adopt HSR of the passengers. Consequently, the number of Potential HSR Adopters decreases and so does the HSR Adopters. The rate of price increase is controlled directly by the managerial decision of the HSR operator to avoid drastic price increase and loss of adopters.

・**Load Factor Management**

In this loop, the average Load Factor is managed directly by supplying the sufficient amount of Available Seats, which are only determined by the operation frequency. The actual LF is compared with the Desired LF (the operator sets the value), and the HSR operator targets the frequency increase to realize the desired level of LF with certain delay of time. If the operator wants to control the LF as quickly as possible, it tries to shorten the required time to increase frequency by long term planning of investing in rolling stock and other facilities. The operator has to balance the increase in cost and its will to suppress the too-high LF (the cost function is out of the scope of this thesis, though).

・**Service Availability**

The supply of the available seats is increased according to the increase of the actual number of HSR Adopters, explained as the Load Factor Management loop, which is considered to be an LF adjustment function. If the increase rate of the HSR adopters unexpectedly exceeds that of the seat supply, then the LF is pushed up and could be higher than the desired level. In this case, the new adopters have difficulties to reserve the preferred seats due to the low Service Availability. As discussed in the previous chapter, one of the advantages of the Japanese-type HSR is its convenience of choosing the train just before the departure time. The low-level of seat availability could lower the HSR's competitiveness, and therefore it can slow down the further increase of the HSR Adopters.

・**Accessibility to Stations**

In this model, we assume the preference of the intercity passengers is affected not by the time on board, but by the Total Travel Time, including access time to the HSR stations, egress time from the stations to the destination, and wait time at the station. When the number of the HSR Adopters increase considerably, and therefore the passengers to access (or egress) the HSR stations by car increases, the Road Congestion and Waiting Time for Parking will exacerbate the situation due to the sudden increase of the Access (and egress) Time to the HSR stations.

This effect will slow down the ridership growth by decreasing Willingness to Adopt HSR in the long run. The private operator should manage this problem by cooperating with the public sector to improve public mass transit system and increase the Public Transportation Fraction.

・**Market Saturation** (as described in Section 8.2.1)

This loop is a part of the Bass Diffusion Model, and it could slow down the stable growth of ridership in the long run. It is important to suppress this feedback effect by increasing a sufficient number of Potential HSR Adopters by letting Passengers Not Willing to Adopt HSR become interested in the HSR service, by controlling the ticket price and time saving.

Reinforcing feedback loops

・**High Frequency Convenience**

In this loop, the convenience of the HSR adopters to have frequent train operation is represented. When frequency increases enough, the HSR Adopters get satisfied with the service attribute because they could choose the preferred train. We assume that the perception of the convenience of high frequency mainly occurs after the first adoption of the HSR service and when considering the repeat use. To keep high retention rate, therefore low Churn Rate, it is necessary that the train frequency hit the certain level that could satisfy the repeat users. In this way, the high frequency due to the increase of HSR Adopters and high LF makes the positive feedback to further increase the Adopters.

・**Decreasing Wait Time**

The frequency increase also contributes to reduce the Average Wait Time at the HSR stations to wait for the next train. This effect can reduce the Total Travel Time and enhance the competitiveness of the HSR system. This pushes up the Willingness to Adopt the HSR due to the increasing time saving, and thus Potential HSR Adopters and actual HSR Adopters increase with a certain delay time. As a result, this process increases the LF and leads to further frequency increase. Of course, there are cost implications of this strategy that we do not consider in this study.

・**Word of Mouth** (as described in Section 8.2.1)

This loop is also a part of the Bass Diffusion Model, which represents the diffusion of the new product in a certain market through the effect of external information such as word of mouth. When the number of the HSR Adopters increases, then the probability of contacts between the Potential Adopters and actual Adopters gets higher, and therefore the Adoption from Word of Mouth increases more and more. We should note that this model does not assume the Adopters communicate a bad opinion of the service and the word of mouth decreases the adoption. We assume that the other attributes of the HSR service (comfort, safety, reliability and so on) have remained at the certain level that is acceptable for the Adopters.

In our model, the HSR operator can actively work on the following three aspects as its managerial decision to affect the other dependent variables (such as ridership):

・**Time Lag in Changing Price and Initial Price**

It is theoretically possible for the operator to increase the ticket price whenever it needs, because the private venture has more autonomy to freely set the price than a public entity has (This is the conclusion from the analysis in Chapter 4). However, drastic price increase may impede the stable ridership growth due to the effect of the balancing loop of Price Increase. The ticket price is indicated by the balance of supply and demand (LF, as described in the Price Increase loop) in this model, and thus the private entity actively controls price's increase rate by adjusting Time Lag in Changing Price. Initial Price is also within the scope of decision-making of the private venture.

・**Time required to Increase Frequency / Desired Load Factor**

The operator can control the frequency increase rate by controlling the time required to increase frequency. If the operator wants to adjust the LF as quickly as possible to the Desired LF, the implementation of the new rolling stocks and other facilities should be provided in a short span of time. We do not consider the cost function of increasing operation frequency in this model, so in the actual decision-making, the operator has to balance the cost and revenue increase from the increasing frequency. The desired level of LF also relies on the managerial decision of the private venture.

・**Target Public Transportation Fraction**

As discussed above, it is vital for the HSR operator to secure the effective access and egress to and from the HSR stations by transportation modes other than car. Public Transportation Fraction is the indicator of how many people use public transportation to move between the stations and origin or final destination. In this model, the private operator can work on this issue by setting Target Public Transportation Fraction, coordinating with the public sector, such as the Texas DOT, the Metropolitan Planning Organizations, and urban public transportation organizations, as discussed in Chapter 4.

These independent variables, which are relevant to the policies (managerial decisions) of the operator, are shown in red in Fig. 8-6.

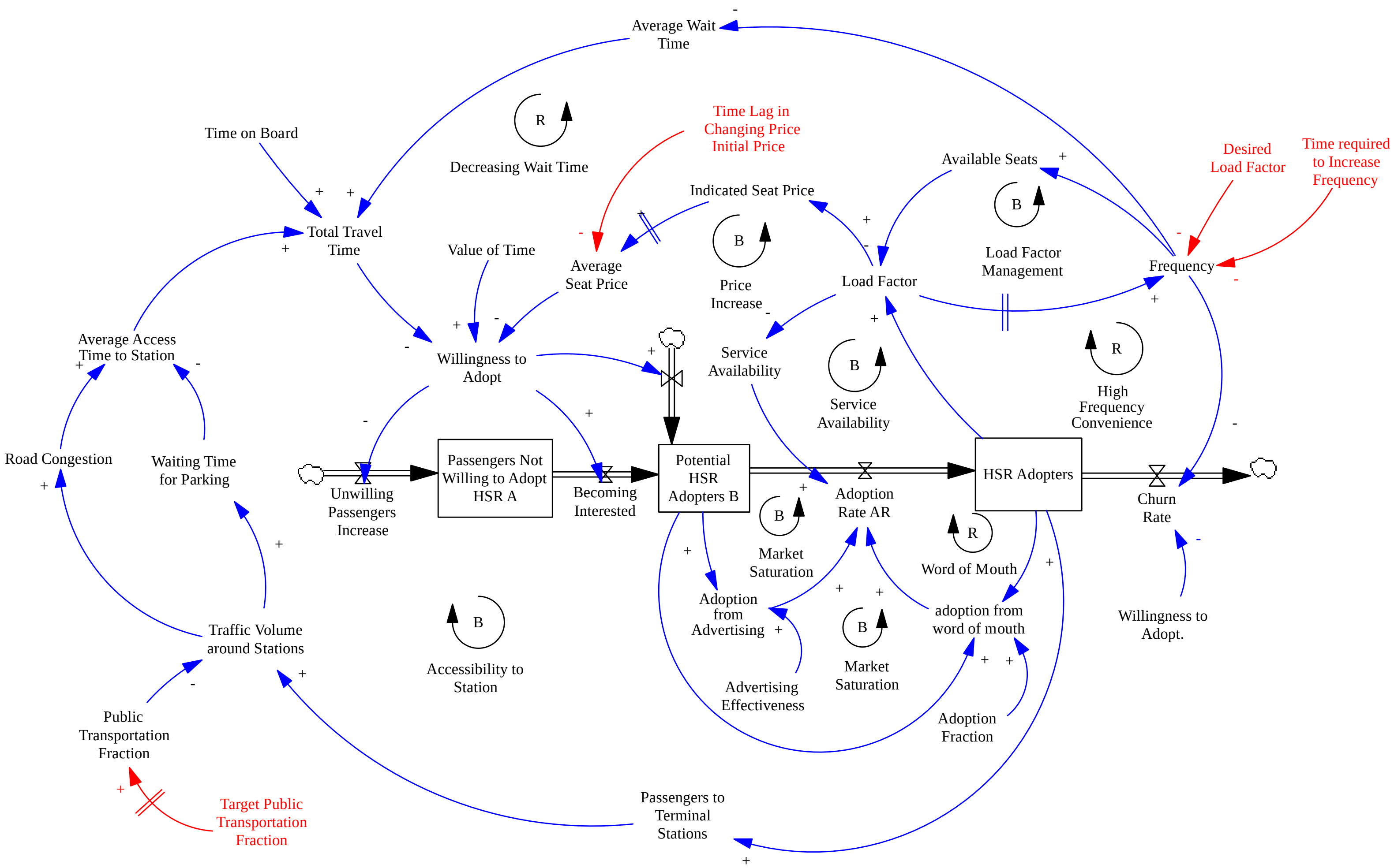


Fig.8- 6 Integrated CLD of the Texas HSR system

8.3 Conclusions from CLD Analysis

The purpose of this CLD analysis is to identify the key factors that improve the Texas HSR system from the viewpoint of the HSR operator. The objective of the project is to secure the stable ridership growth and enhance the revenue in the long run, because this project is promoted by the private venture, and so the profitability is the most important feature. As this research focuses on the balance of demand and supply of the transportation service, it does not include the cost estimation. Consequently, the objective variables of this SD model are the number of HSR Adopters and the revenue from the ticket.

From the integrated CLD, we identify three key indicators affecting these objective variables: Average Seat Price, Total Travel Time and Load Factor. The first two indicators are relevant to the competition with other modes: airline industry and highway. If the time saving of using the HSR, compared with the main competitors, could justify the price difference between the other modes and the HSR, intercity passengers become interested in the HSR adoption based on their VOT. Once they become interested and therefore Potential HSR Adopters, they are affected by the Load Factor in terms of service availability. When the service availability is high enough, then they actually adopt the HSR. The CLD shows that some of the adopters stop using HSR considering its frequency, travel time and seat price, so the three key indicators have an impact on the ridership growth again.

These three indicators are directly affected by independent variables that are relevant to the operator's policy (decision). Average seat price is determined as a result of the managerial decisions for the initial ticket price and time lag in changing price. The operator can reduce total travel time by targeting high value of public transportation use to access the HSR stations, and by increasing the operation frequency. Load factor is adjusted to the desired level, which also depends on the operator's managerial decision, by increasing frequency of the trains.

In the following discussion, the results of the SD simulation are mainly discussed with regards to these objective variables, key indicators and independent variables.

8.4 Creating Numerical SD Model

The CLD we created in the previous section is now turned into a numerical SD model to conduct quantitative estimation for the Texas HSR case. In this section, the numerical SD model and its mathematical formulae are shown for the main adoption part and each subpart.

8.4.1 The Adoption Part

・**Value of Time (VOT) and Fraction Willing to Adopt**

The adoption part is based on the Bass Diffusion Model. One of the additional components in the adoption part is Value of time (VOT) of the intercity passengers. In this model, the VOT is a threshold for the passengers to be willing to adopt HSR or other travel modes. According to the USDOT's guidance [130] there are two groups of people who have different VOTs: private intercity travellers and business intercity travellers. To estimate the distribution of the VOT in the intercity travel market between Houston and Dallas, we assume that the mean value is the median of each range, and the VOT of each group is normally distributed around the mean value, as shown in Table 8-1.

Table 8- 1 Assumed distribution of VOT in the intercity travel market in Texas

	Percentage	Range of VOT [$/h]	
		Low	High
Private use	59.6%	28	42
Business use	40.4%	48	72
*Intercity passengers who use air or HSR		*Air and HSR Traveler	

Assumption	
Mean	σ
35	3.5
60	6
Standard Normal Distribution	

* recommendation values of USDOT guidance, 2014

According to this assumption, the upper graph of Fig. 8-7 shows that there are two peaks of VOT distribution because of these two categories of private and business users. In the SD model, the cumulative proportion is implemented in the Value of Time Look Up, as shown in the graph below, to refer to the proportion of passengers who are willing to adopt HSR, by calculating the Value of Time Threshold from actual time saving and ticket price. For example, when the time saving of HSR is 2 hours and the ticket price is $80, then the value of time threshold is 40[$/hour]. The cumulative proportion of passengers who are willing to adopt HSR is slightly above 40%. This is consistent with the red shaded area in the graph above. When the value of time threshold is less than 25 [$/hour], the cumulative proportion is 100%, and the value is over 75 [$/hour], the cumulative proportion is 0% in this model. We consider this cumulative proportion as the Fraction Willing to Adopt (FWA) HSR service.

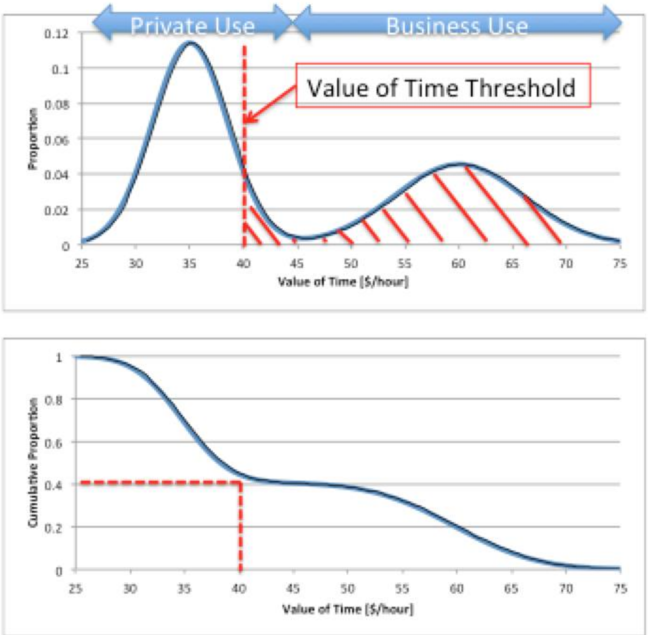


Fig.8- 7 The assumed distribution of Value of Time in the intercity travel market

Based on this VOT reference table, the FWA is determined by the Price Difference divided by the Total Travel Time Difference of the HSR and the reference mode of transportation. In this model, <u>we assume the main competitor of the HSR is a highway user</u>, because the passenger market is almost dominated (over 90%) by the highway. Therefore, the reference value for the price is set to constant value $35, which is calculated from the monetary cost of unit oil price and the average vehicle fuel consumption of a private car to drive 240 miles between Houston and Dallas [120] [121]. The reference value of "Total Travel Time of using Car" to move from Dallas to Houston is based on the estimation of the Texas DOT. Travel time between these two cities by driving a private car will be expected to increase to over 6 hours in 2050 from 3.5 hours in 2015, due to the heavy congestion mainly on I-45 [24] [27]. We assume that the travel time of a car user is 4 hours in 2022, increasing 4.3 minutes annually, and finally reaching 5.5 hours in 2042, as shown in Fig. 8-8. As a result, the Average Seat Price of HSR and Total Travel Time of HSR is calculated in the Pricing subpart and Total Travel Time subpart.

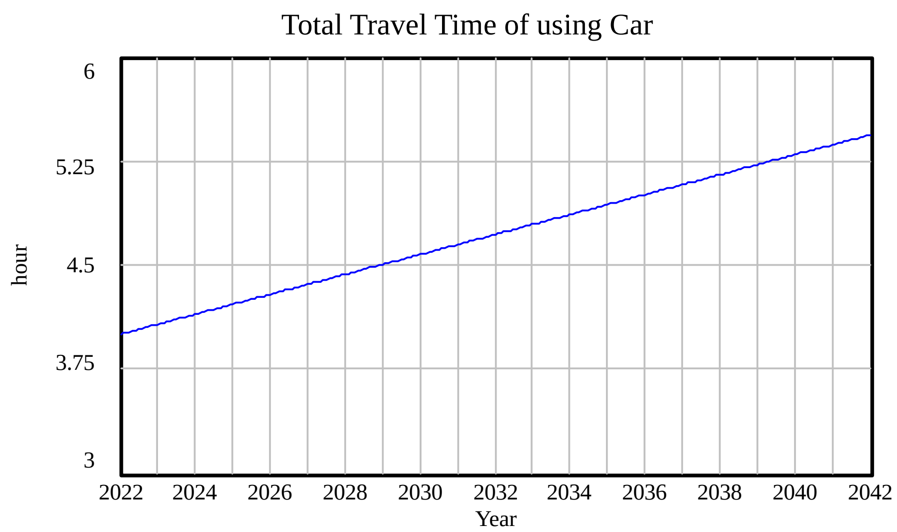


Fig.8- 8 The assumed Total Travel Time of using Car

・**Passengers Not Willing to Adopt and Potential HSR Adopters**

The Bass Diffusion Model is modified to represent all of the intercity passengers divided into three categories: Passengers Not Willing to Adopt, Potential HSR Adopters, and HSR Adopters, as shown in Fig. 8-2. The number of each variable is calculated on a monthly basis for 20 operation years after the scheduled commencement in January in 2022. The Fraction Willingness to Adopt (FWA) is the indicator of how many people are willing to adopt the HSR service in terms of time saving and cost. Thus, the ratio of Passengers Not Willing to Adopt and the sum of Potential HSR Adopters and HSR Adopters is adjusted with certain time of delay, Time to Adjust Willingness. The rate of Becoming Interested, which is the people's transition pace from Passengers Not Willing to Adopt to Potential Passengers, is determined according to the following equations:

$$\text{Total Passengers} = \text{Passengers Not Willing to Adopt} + \text{Potential HSR Adopters} + \text{HSR Adopters} \quad \text{[person]}$$

$$\text{Becoming Interested} = \frac{(\text{Total Passengers} \times \text{FWA} - (\text{HSR Adopter} + \text{Potential HSR Adopters}))}{\text{Time to Adjust Willingness}} \quad \text{[person/month]}$$

Between Houston and Dallas areas, the intercity passenger market is predicted to grow from 16 million trips in 2022 to over 27 million trips in 2050 (1.89% per year in average) [88]. The Net Passengers Increase of the intercity transportation market is added to the stocks of Passengers Not Willing to Adopt and Potential HSR Adopters following the ratio of FWA:

$$Potential\ Adopters\ Increase\ =\ Net\ Passengers\ Increase \times FWA \qquad \text{[person/month]}$$

$$Unwilling\ Passengers\ Increase\ =\ Net\ Passengers\ Increase \times (1 - FWA) \qquad \text{[person/month]}$$

Fig. 8-9 shows the growing Total Passengers between 2022 and 2042. The intercity passenger market is assumed to grow from 1.33 million trips per month to more than 1.9 million trips within 20 years. The line in the figure is seemingly linear, but the number of intercity passengers increases nonlinearly, which means the market grows exponentially.

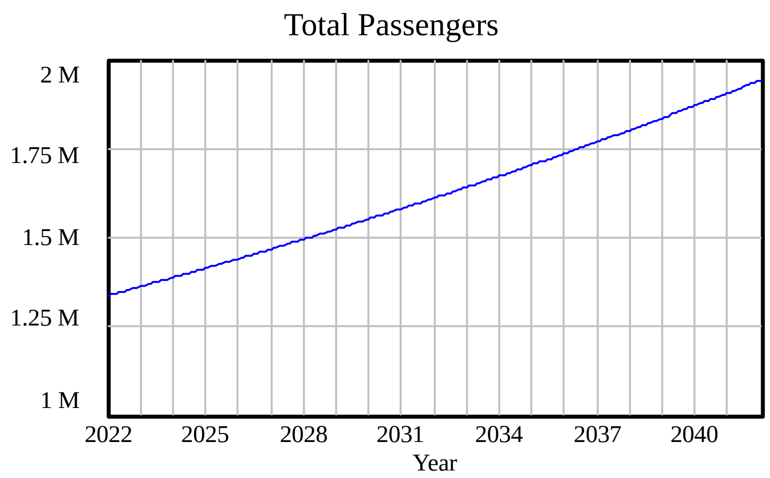


Fig.8- 9 Expected intercity passenger market growth between the North Texas and Houston areas (1.89% annually)

・**HSR Adopters**

The stock of HSR Adopters is changing according to the following equation:

$$\text{HSR Adopters} = \text{Initial Adopters} + \int_0^t (\text{Adoption Rate AR} - \text{Churn Rate CR})\, dt \text{ [person]}$$

In the Bass Diffusion Model, The Adoption Rate (AR) is the sum of the Adoption from Advertising (AA) and Word of Mouth (AW) [137]. In this model, we consider Service Availability (0 to 1, the function of Load Factor) affecting the AR as discussed in the previous section, and a certain time delay, Time to Adopt. The AR is calculated as follows:

$$\text{Adoption Rate AR} = \left(\frac{\text{Adoption from Advertising} + \text{Adoption from Word of Mouth}}{Time\ to\ Adopt}\right) \times Service\ Availability \text{ [person/month]}$$

The AA is influenced by the number of Potential HSR Adopters and Advertising Effectiveness (a), which is an exogenous input parameters.

$$\text{Adoption from Advertising AA} = \text{Advertising Effectiveness a} \times \text{Potential HSR Adopters} \text{ [person/month]}$$

The AW is influenced by the Adoption Fraction, which is "[t]he proportion of contacts that are sufficiently persuasive to induce the potential adopter to adopt" HSR service [137], and the probability of contacts between the HSR Adopters and the Potential Adopters in the regional communities which have an increasing Total Population (N). This probability is calculated as the product of Contact Rate (c) and the encounter probability as follows:

$$\text{Adoption from Word of Mouth AW} = \text{Adoption Fraction i} \times \text{Contacts with Adopters CA} \text{ [person/month]}$$

$$\text{Contacts with Adopters CA} = \frac{Contact\ rate\ c \times Potential\ HSR\ Adopters \times HSR\ Adopters}{Total\ Population\ N} \text{ [person/month]}$$

We assume that the Churn Rate (CR) is affected by two factors. The first factor is the Fraction Willing to Adopt (FWA), which is the function of Price Difference and Total Travel Time Difference. If the ticket price increases, some HSR Adopters stop using HSR due to the decreasing FWA, and become Passengers Not Willing to Adopt with no time lag (= 1 month)[3]. The other factor is the disappointment at the inconvenience of low Frequency. The Effect of Frequency on Defection is based on the Customer Defection model, which compares the desired level of Frequency with the actual level and includes unknown Elasticity of Frequency on CR [137]. This defection happens with a certain time delay, Time lag in CR. The CR is the sum of defection rate from these two factors, and is defined as follows:

$$\begin{aligned}\text{Churn Rate} \;=\; & \text{HSR Adopters} \times (1 - \text{FWA}) \;/\; \text{Unit time lag} \\ & + \text{HSR Adopters} \times \text{Effect of Frequency on Defection} \;/\text{Time lag in CR}\end{aligned}$$

[person/month]

$$\text{Effect of Frequency on Defection [dimensionless]}$$
$$= \begin{cases} 0 & (if \text{ Frequency } > \text{ Desired Frequency}) \\ (1 - \dfrac{\text{Frequency}}{\text{Desired Frequency}})\text{\textasciicircum Elasticity of Frequency on CR} & (if \text{ Frequency } \leq \text{ Desired Frequency}) \end{cases}$$

In Fig. 8-10, eight input parameters, Advertising Effectiveness, Adoption Fraction, Contact Rate, Time to Adjust Willingness, Time to Adopt, Time lag in CR, Desired Frequency and Elasticity of Frequency on CR, are shown in blue. We estimate these variables in Section 8.5.

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[3] HSR Adopters are likely to have a larger VOT than the VOT threshold since they have already adopted HSR once, but we assume they are also affected by the Fraction Willing to Adopt to take into account the effect of price increase on the Churn Rate.

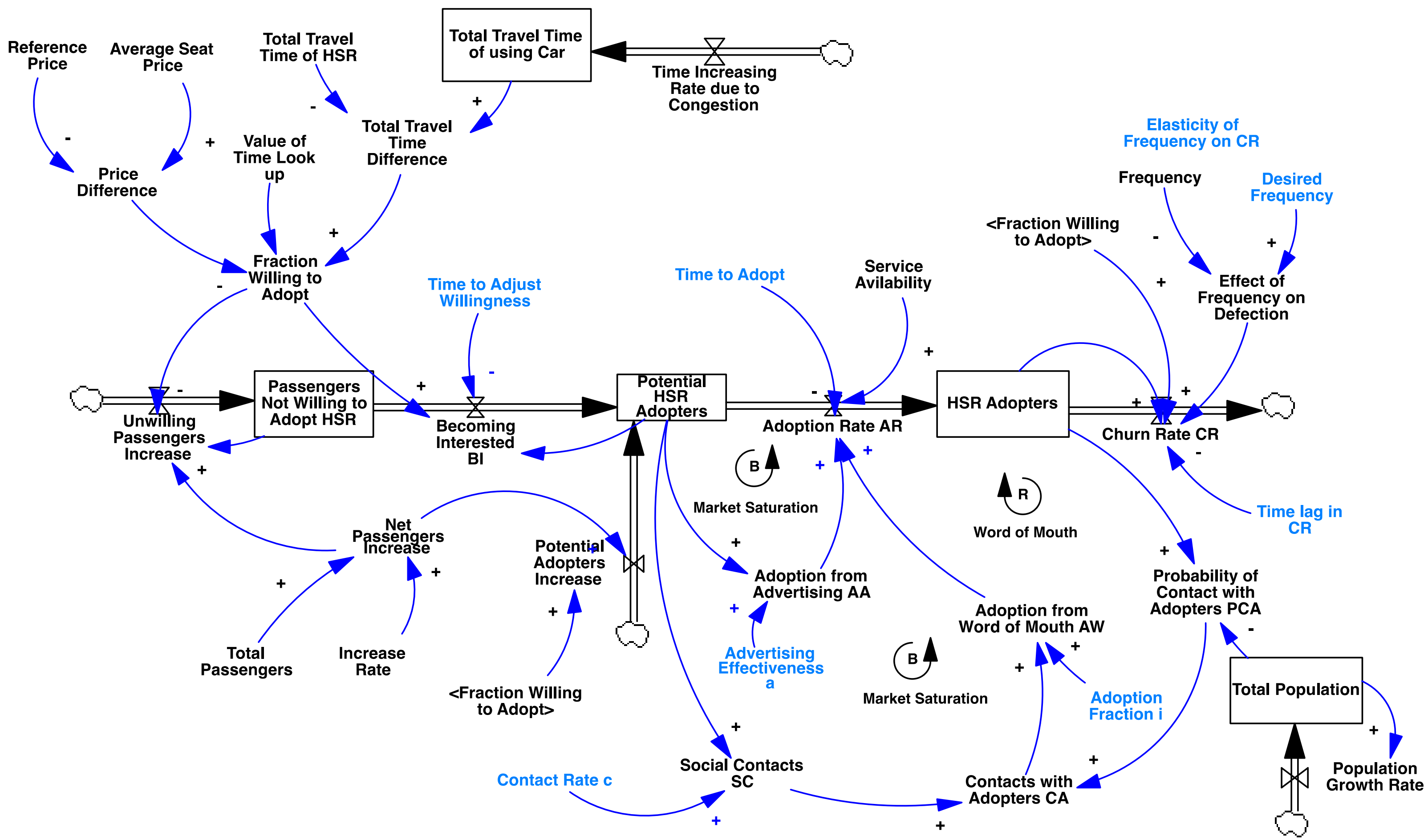

Fig.8- 10 Adoption part of the numerical model

8.4.2 Pricing Subpart

The Average Seat Price of the HSR is determined based on a "Hill-Climbing Optimization" model, which adjusts the actual price to the Indicated Seat Price based on the comparison of actual Load Factor (LF) with Reference LF (target). The Effect of LF on Price is the function of Actual LF and Reference LF (target LF) and adjusts the Indicated Seat Price to suppress the higher LF below the target value by increasing the seat price. For the managerial decision of the operator, Initial Price, Pricing Increase Switch (equals 0 if it does not want to increase the price at all, and equals 1 if it does) and Time lag in Changing Price are implemented, as shown in red in Fig 8-11. The equations are as follows:

$$\text{Price Changing Rate} = \text{Pricing Increase Switch [0 or 1]} \times \frac{(Indicated\ Seat\ Price - Average\ Seat\ Price)}{Time\ lag\ in\ Changing\ Price}$$ [4]

[$/month]

Indicated Seat Price = Effect of LF on Price × Average Seat Price [$]

$$\text{Effect of LF on Price} = \left(\frac{Actual\ LF}{Reference\ LF}\right)^\wedge\ LF\ Sensitivity\ on\ Price$$

LF Sensitivity on price is an input parameter shown in blue in Fig. 8-11. This parameter is to be estimated in Section 8.5. Also, Monthly Revenues from the ticket income are calculated by multiplying the Average Seat Price and the number of HSR Adopters for each month in this subpart. Cumulative Revenue is the accumulation of these monthly revenues.

[4] In this model, the ticket price is not decreased to the price less than the initial value. The LF usually does not hit the desired level for the first few years. In this case, the operator waits to increase the price until the ridership grows and the LF hits the desired level.

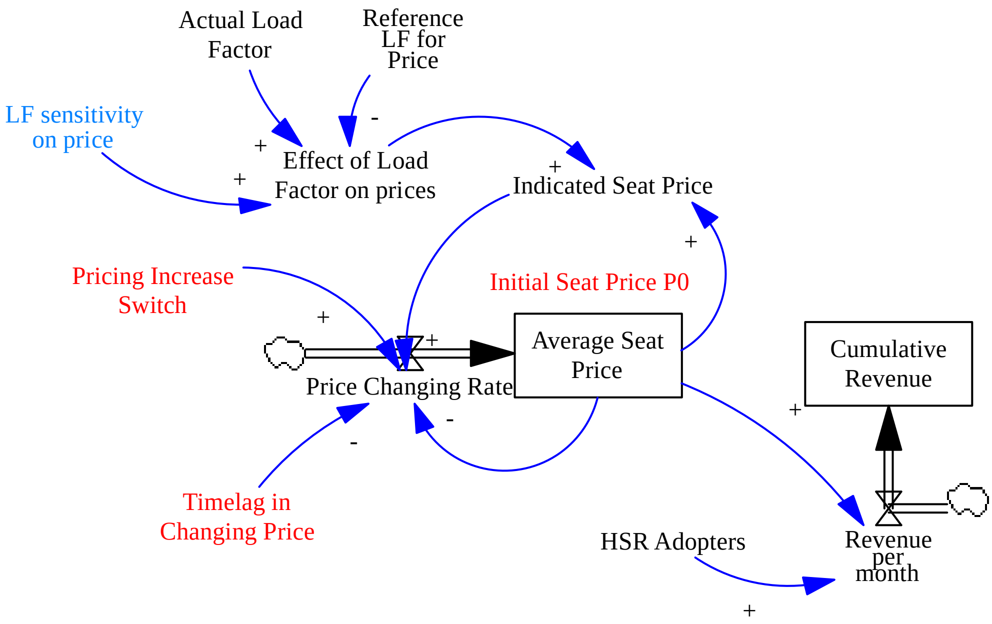

Fig.8- 11 Pricing subpart of the numerical model

8.4.3 Capacity Subpart

The Capacity subpart is created based on the "Adjustment to a Goal" model, which targets the Desired Load Factor set by the operator and changes the Frequency to the Target Frequency with a certain time delay, in order to adjust the LF to the desired level [137]. The larger the difference between the Desired and Actual LF is, the greater the Frequency changes to close the gap between these values. Frequency Increase Rate is calculated as follows:

$$\text{Frequency Increase Rate} = \frac{(\text{Target Frequency} - \text{Frequency})}{\mathit{Time\ Required\ to\ increase\ Frequency}}$$

$$\text{Target Frequency} = \frac{\text{Actual Load Factor}}{\text{Desired Load Factor}} \times \mathit{Frequency}$$

$$\text{Actual Load Factor} = \frac{\text{HSR Adopters}}{\text{Available Seats}} = \frac{\text{HSR Adopters}}{\mathit{Capacity\ per\ Train}^{5} \times \mathit{Frequency}}$$

[5] Capacity per train is set constant at 400 seats per train for the Texas HSR.

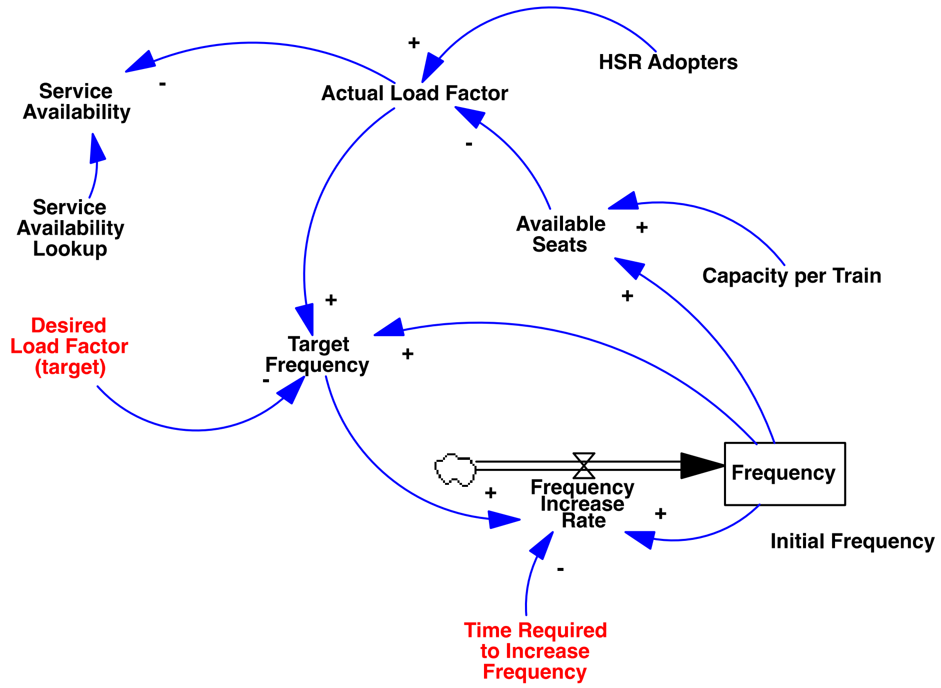

Fig.8- 12 Capacity subpart of the numerical model

Then, we introduce the Service Availability as a monotonically decreasing function of the Actual Load Factor. Several studies show that the number of passengers' "rejection[s]" to reserve HSR ticket closely relates to the average load factor of the intercity passenger train, and they proposed the flexible seat allocation to reduce the possibility of the refusals [143] [144]. We assume the Service Availability follows a reverse S-shape curve, which is characterized as a logistic function. This is a monotonically decreasing function of Load Factor, which is shown in Fig. 8-13. This reflects the idea that the service availability could be almost 1 (100%), when the load factor is low enough and there are many options for the passengers to reserve the preferred seats. The Service Availability gradually decreases when the LF gets higher than a certain level (in this model, around 50%), due to the increasing possibility of reservation rejection. When the LF gets closer to a certain high level (75%), the availability decreases drastically. Finally, if the average LF gets higher than 90%, it is difficult for the new HSR Adopters to adopt the HSR service. The formulation of the model is as follows:

$$Service\ Availability = f(Actual\ Load\ Factor) = 1 - \frac{1}{1+exp(-a(LF-b))} \quad \text{(a, b: parameter)}$$

Based on the initial operation pattern (two trains per hour during peak hour), about 50% of the HSR adopters will be predicted to use the HSR system during the peak hours. If trains operated during peak hours have 100% load factor and other trains have 50% load factor, then the average load factor will be around 75%. In this case, the HSR adopters who are willing to use the service during peak hours cannot find their seats. Based on this assumption, the Service Availability is set at 50% when the LF hits 75%. These assumed values are stored in a form of reference table in Service Availability Look Up.

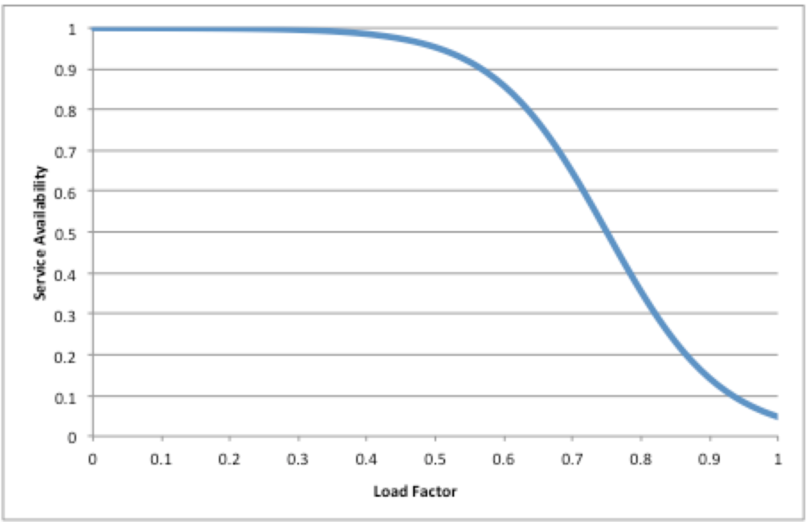

Fig.8- 13 Assumed Service Availability function changed with Load Factor

As a result, the capacity subpart adjusts the operation frequency to the desired level by using the LF as an indicator, and by doing so it keeps the service availability high enough so that the potential HSR adopters could adopt the service. The operator can affect this subpart by changing the Desired LF and Time Required to Increase Frequency, which are shown in red in Fig. 8-12.

8.4.4 Total Travel Time subpart

In this subpart, the Total Travel Time of HSR users is calculated. We assume that the HSR Adopters access the HSR stations by either car, including taxi and ride sharing service, or public transportation (PT). The total travel time is defined as follows:

$$Total\ Travel\ Time\ of\ HSR = Time\ on\ Board + Average\ Waiting\ Time + Average\ Access\ Time$$

[hours]

Time on Board is fixed at 90 minutes. The Average Waiting Time is assumed as half of average headway during operation hours; therefore it is a function of Frequency. Average Access Time to Stations consists of two parts: Access time by Car and by Public Transportation. These two Access times are proportioned by Public Transportation Fraction, which is the ratio of PT users and car users, to calculate the average access time. The equation is as follows:

$$Average\ Access\ Time\ =\ PTFraction \times Access\ Time\ by\ PT + (1 - PTFraction) \times Access\ Time\ by\ Car \quad \text{[hours]}$$

While Access Time by PT is constant, Access Time by Car increases when the increase of Passengers to Terminus Stations cause an increase in Traffic Volume, and thus the road and parking congestion around the stations get worse. To model these congestions, we use the simple bottleneck model, using Road and Parking Facility Capacity as a bottleneck causing congestion [145]. The equations are as follows:

$$Average\ Access\ Time\ by\ Car = Initial\ \ Access\ Time\ +\ Delay\ of\ Road\ Congestion\ +\ Delay\ in\ Parking \quad \text{[hours]}$$

$$Delay\ of\ Road\ Congestion = \begin{cases} 0, & (Traffic\ Volume < Road\ Capacity) \\ \frac{1}{2}(\frac{Traffic\ Volume}{Road\ Capacity} - 1), & (Traffic\ Volume \geq Road\ Capacity) \end{cases}$$

$$Delay\ in\ Parking = \begin{cases} 0, & (Traffic\ Volume < Parking\ Facility\ Capacity) \\ \frac{1}{2}(\frac{Traffic\ Volume}{Parking\ Facility\ Capacity} - 1), & (Traffic\ Volume \geq Parking\ Facility\ Capacity) \end{cases}$$ [6]

The Public Transportation Fraction is the ratio of passengers choosing PT for the access to the HSR stations, and this ratio is determined based on the probabilistic binary choice model [119]. Traffic Volume to access the stations is affected by the PT Fraction, as follows:

$$\text{Public Transportation Fraction} = \frac{\text{Exp (Public Transportation Utility)}}{Exp(Private\ Car\ Utility)\ +\ Exp(Public\ Transportation\ Utility)}$$

[6] In this model, as an assumption of facility constraint, Road Capacity is set to 4000 [cars/ day] and Parking Facility is set to 2500 [cars/day].

$$\text{Traffic Volume} = \frac{\text{HSR Adopters} \times (1 - \text{PT Fraction})}{\textit{Average Vehicle Occupancy}^{7}} \qquad \text{[Cars/day]}$$

In this model, Private Car Utility is changing as a function of the ratio of Initial Access Time by Car and the Average Access Time to Stations by Car with a certain time delay. When the congestion gets worse and the access time to the stations by car increases compared with the initial access time, the utility of the car decreases. Public Transportation Utility is adjusted to the value that realizes the Target PT Fraction with a certain time delay. The initial PT Fraction is set at 25%, based on the environmental impact assessment report predicting, "Approximately 75% of passengers arrive by cars"[31]. The HSR operator could target higher PT Fraction as its managerial decision, cooperating with the public sector by implementing PT access to the HSR stations. Therefore, the Target PT Fraction, shown in red in Fig. 8-14, is an independent variable relating to the managerial decisions of the operator.

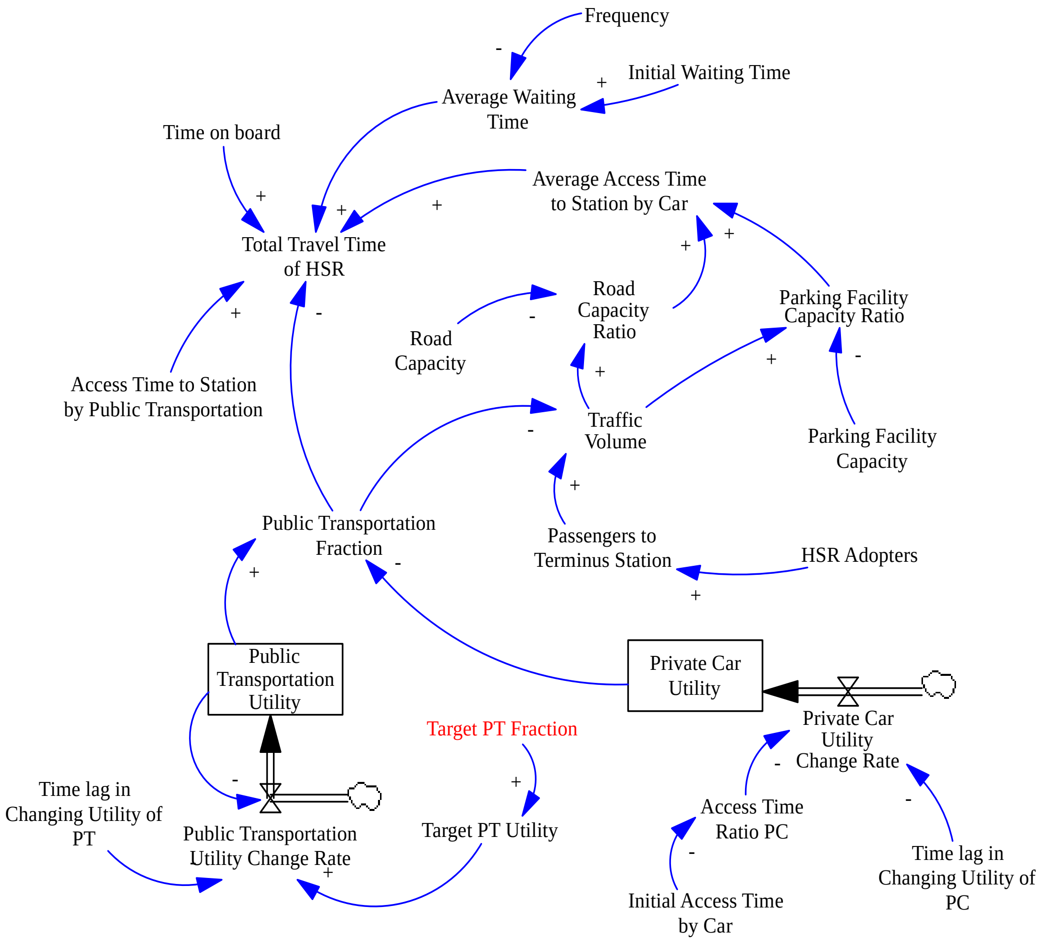

Fig.8- 14 Total travel time subpart of the numerical model

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7 Average Vehicle Occupancy Rate is set to 1.6 based on the DOE report. [146]

8.5 Model Calibration by Using the Taiwan HSR Data

The purpose of this section is to conduct "Behavior Reproduction Tests" to validate the structure of the numerical model we created in the previous chapter [137]. Some of the exogenous variables in the numerical SD model have input parameters, which are used to create numerical equations. The values of these variables are estimated in this section by comparing the simulation results with historical data from the Taiwan HSR case. It should be noted that we assume the basic structure and behavior of the SD model, which is trained by the historical data in the Taiwan HSR (ridership, frequency and modal share), is also applicable to the Texas HSR. This assumption is based on the fact that there are many important similarities between the two HSR lines especially in their demand-developing phase, as discussed in Chapter 6. The model applied to the Taiwan case has the same model structure as the Texas case, and some exogenous variables (Value of time, total travel time of HSR, Population and so on) are changed to conduct the simulation. For example, we assume the VOT in Taiwan has a similar distribution to that of Texas, based on the fact that the targeted market segments in both cases have similar component ratios: 40% for business travel and 60% for personal (for Texas, the assumed VOT distribution is shown in Fig. 8-7). According to the USDOT guidance of VOT, it is affected strongly by the average hourly wage of the region [130]. Thus, the VOT in Taiwan is adjusted to 27% of that in the US based on international statistics of the average hourly compensation costs [147]. The comparison of these modified variables is shown in Table 8-2.

In the model-training step, we calibrate the model by using an optimization method to minimize the Sum of Squared Errors (SSE) of prediction between the actual data of the real HSR case and the results of the simulation. The fitness of the data and the simulation results are mainly evaluated by the Coefficient of Determination (R^2), which is the statistical indicator showing the proportion of a variance in the data. Sterman noted that "The most widely reported measure of fit is R^2" which is used to conduct "Behavior Reproduction Tests" whose purpose is to reproduce system behavior by fitting the simulation results to real data [137]. Additionally, a 95% confidence interval for each parameter is estimated.

We compare three data sets of interest in the Taiwan HSR to the simulation results: ridership, frequency and modal share. The estimated data used for the comparison are the number of passengers and operation frequency from 2007-2016, and the HSR modal share from 2007-2008 [104][132]. The estimation of the input parameters is conducted based on the assumption that the access time to the HSR stations in Taiwan is constant using public transportation. This assumption is based on the fact that public transportation networks were well developed in Taipei and Kaohsiung at the time of the HSR's inception in 2007 [104].

Table 8-3 shows the estimated values for each input parameter by using the optimization method mentioned above. For each input parameter, 95% confidence interval is also shown. Fig. 8-15 shows the comparison of the number of HSR Adopters, and operation frequency and modal share between the data (gray, black and red lines) as well as the results of the numerical simulation (blue lines). The comparisons of the three variables show that the overall trends of the actual data are well captured in the numerical model. The model tracks the actual data relatively well, showing a high value of R^2 for the number of HSR adopters and frequency. The discrepancy between the data and the simulation results of modal share is due to a shortage of modal share data (only 1 year of estimated data).

These estimated values of the input parameters could be interpreted as follows:

・56% of potential adopters are affected by the advertising and adopt the service.

・30% of contacts between potential adopters and actual users are sufficiently persuasive to let potential adopters actually use the HSR service.

・An HSR adopter contacts with a potential HSR adopter at the rate of 42 times per month.

・Time lag in changing willingness to adopt and to actually adopt are 2.9 and 2.5 months.

・Time lag in churn rate is almost one month. It is shorter than the time lags mentioned above, therefore adopters stop using HSR relatively sooner than they adopt it.

・Desired frequency by the adopters is over 1600 trains per month, which is about 27 trains per day per one way.

These estimated input parameters are used for the sensitivity analysis of the Texas HSR in the next section.

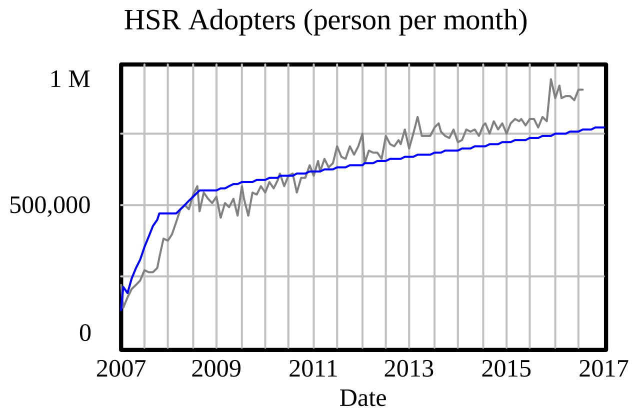
Table 8- 2 Comparison of exogenous variables for Taiwan and Texas

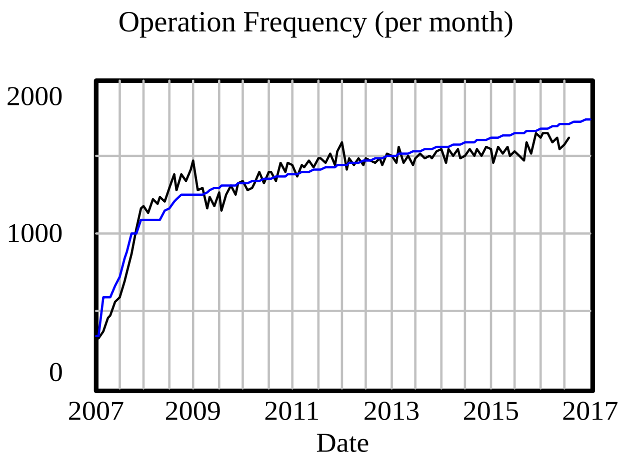
Variable in Simulation	Taiwan	Texas
Ratio of Value of Time	27 (in 2012)	100
Annual Net Increase Rate of the intercity passenger market	+4.59 [%/year] (during 2005-2008)	+1.89 [%/year] (predicted growth during 2022-2050)
Population Growth in regions (Taipei-Kaohsiung and Houston- Dallas FW)	+0.43%	+1.5% [%/year]
Average Seat Price (Initial)	$46 (Average price of business and coach seats)	$60 - $120 (parameter)
Reference Price (main competitor)	$22 (intercity bus fare)	$35 (private car users)
Travel Time (using public transportation)	94 minutes on board 30 minutes access/egress time	90 minutes on board 45 minutes access/egress time
Total Travel Time of using Car (main competitor's total time)	5.5 hours (including assumed access time to bus stops)	4 hours (initial, in 2022) +7.2% increase annually

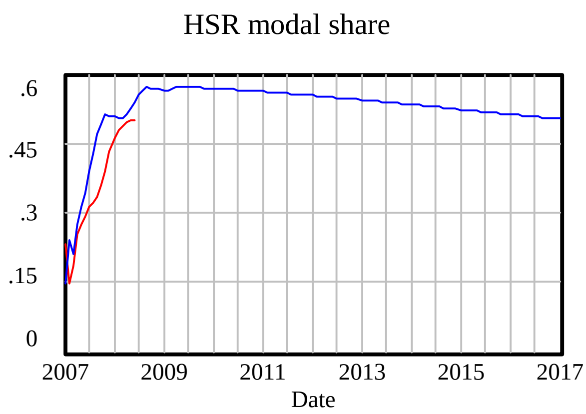
(Created by the author based on references [21] [27] [88][104][123] [132])

Table 8- 3 Estimated values for input parameters

Estimation of the unknown variables	Input Parameters	estimated value	95% confidence interval	
			lower	upper
Adoption part	Advertising Effectiveness a [1/month]	0.5574	0.5572	0.5577
	Adoption Fraction i	0.2986	0.2983	0.299
	Contact Rate c [1/month]	41.61	41.57	41.66
	Time to Adjust Willingness [month]	2.912	2.904	2.922
	Time to Adopt [month]	2.5	2.49	2.51
	Time Lag in Churn Rate [month]	1.014	1.013	1.015
	Desired Frequency [1/month]	1606	1605	1607
	Elasticity of Frequency on CR	2.213	2.211	2.214
Pricing subpart	LF Sensitivity on Price	0.1374	0.1373	0.1377







(blue line shows the results of the simulation)

	R Squared
HSR Adopters [person/month]	0.83
Operation Frequency [1/month]	0.91
HSR Modal Share	0.55

Fig.8- 15 Comparison of simulation results and data in the Taiwan HSR case

8.6 Application of SD Model to Texas HSR Case: Sensitivity Analyses

In this section, a sensitivity analysis for each input and policy parameter in the numerical model for the Texas HSR case is conducted. As the first step, we conduct sensitivity analyses for the input parameters estimated in the previous section (such as Advertising Effectiveness, Adoption Fraction, etc.) as shown in Table 8-4. This sensitivity analysis "test[s] the robustness" [137] of model behavior in terms of uncertainties included in the estimated values. We evaluate the impact of 20% changes on ridership growth for each of the nine input parameters. In the next step, we conduct sensitivity analyses for the policy parameters, which are relevant to the three strategic alternatives (pricing, capacity management, and accessibility management) of the HSR operator, to predict how these variables affect system performance of the Texas HSR project. In the previous chapter, we identified the values of Average Seat Price, Load Factor and Total Travel Time as the key indicators of the system's performance. Thus, we conduct sensitivity analyses by changing a ticket's initial price, price increase rate, frequency increase rate, desired load factor, and target proportion of public transportation users to access the HSR stations. These options directly affect the key indicators, and therefore the overall performance and behavior of the system. For these sensitivity analyses, numerical simulation is conducted on a monthly basis for 20 years (240 months). The time horizon is from January 2022, when the operation will be scheduled to start, to January 2042.

Table 8- 4 Input and Policy parameters in the numerical model

Part/ Subpart	Nine Input Parameters	Estimated Value	Part/ Subpart	Five Policy Parameters	Base Value
Adoption part	Advertising Effectiveness a [1/month]	0.558	Pricing subpart	Initial Seat Price [$]	100
	Adoption Fraction i	0.299		Time lag in Increase Price [$]	1
	Contact Rate c [1/month]	41.6	Capacity subpart	Time required to increase Frequency [month]	1
	Time to Adjust Willingness [month]	2.91		Desired Load Factor	60%
	Time to Adopt [month]	2.50	Accessibility subpart	Target Public Transportation Fraction	25%
	Time Lag in Churn Rate [month]	1.01	Simulation is conducted from 2022 to 2042 on a monthly basis (240 months)		
	Desired Frequency [1/month]	1606			
	Elasticity of Frequency on CR	2.21			
Pricing subpart	LF Sensitivity on Price	0.137			

8.6.1 Sensitivity Analyses for the Estimated Input Parameters

As Sterman noted, “Sensitivity analysis asks whether your conclusions change in ways important to your purpose when assumptions are varied over the plausible range of uncertainty.” [137] In the previous section, we estimated the reasonable values for nine input parameters by comparing the simulation results with actual data in Taiwan. We use these estimated values for the analysis of the Texas HSR case as well. Since the estimated values in Texas and Taiwan are likely to be different (for example, the strength of word of mouth effect may not be the same in Taiwan and Texas), it is necessary to anticipate a considerable amount of uncertainty in the estimated parameters. The purpose of this section is to estimate how these probable uncertainties affect the results of system performance. Thus, we conduct sensitivity analyses for the nine input parameters whose values are estimated in the previous section, by the range of plus/minus 20%, as shown in Table 8-5. We should note that in terms of Desired Frequency, which affects the Churn Rate of the HSR Adopters by the effect of reinforcing loop of high frequency convenience, we use a specially modified value of 7420 [1/month] to estimate the sensitivity. This is because the estimated value of the Desired Frequency from data in Taiwan is 1606 [1/month], as shown in Table 8-3. The initial frequency in Texas is set at 1525 [1/month] and the difference between the initial and desired frequency is very small from the beginning. Thus, the effect of the input parameters is too small to evaluate if we use the estimated value 1606 [1/month] for the Desired Frequency. So, we adopt the same ratio of the Desired and Initial Frequency by setting the value at 7420 [1/month] (The initial frequency of Taiwan is 330 [1/month], and the ratio of initial and desired frequency is about 4.87). Also, the estimated Time Lag in Churn Rate value is nearly 1 [month]. This value represents the time delay of churn rate due to the unsatisfactory of the low frequency, so technically it cannot be smaller than 1 month; therefore we change this value only for larger value.

Table 8-6 shows the results of the sensitivity analyses on ridership growth for three different time horizons. Ridership figures when each parameter is changed plus/minus 20% for the years 2025, 2032 and 2042, are compared with that of base case. The results are shown as actual numbers and percent change from the base case. This shows the parameters’ magnitude of impact on ridership in the short to long term. From these results, we can identify several key aspects of each parameter’s sensitivity on ridership.

Table 8- 5 Sensitivity analyses for the nine input parameters

Estimation of the unknown variables	Input Parameters	base value used for Texas	Changing range −20%	Changing range +20%
Adoption part	Advertising Effectiveness a [1/month]	0.558	0.446	0.669
	Adoption Fraction i	0.299	0.239	0.358
	Contact Rate c [1/month]	41.6	33.3	49.9
	Time to Adjust Willingness [month]	2.91	2.33	3.49
	Time to Adopt [month]	2.5	2.0	3.0
	Time Lag in Churn Rate [month]	1.01	–	1.22
	Desired Frequency [1/month]	7420	5940	8900
	Elasticity of Frequency on CR	2.21	1.77	2.66
Pricing subpart	LF Sensitivity on Price	0.14	0.11	0.16

Table 8- 6 Results of sensitivity analyses

(Orange: more than 10% change, yellow: more than 5% change than base case)

Input Parameters	range	Value	HSR Adopters [per month] in Jan 2025 3 years later	%change	in Jan 2032 10 years later	%change	in Jan 2042 20 years later	%change
Advertising Effectiveness a [1/month]	−20%	0.446	120,500	−11.4%	431,300	−6.6%	843,800	−3.9%
	base	0.558	136,000	–	461,800	–	878,400	–
	+20%	0.669	149,000	9.6%	490,900	6.3%	904,300	2.9%
Adoption Fraction i	−20%	0.239	132,800	−2.4%	441,300	−4.4%	851,600	−3.1%
	base	0.299	136,000	–	461,800	–	878,400	–
	+20%	0.358	139,200	2.4%	473,600	2.6%	887,400	1.0%
Contact Rate c [1/month]	−20%	33.3	132,800	−2.4%	441,300	−4.4%	851,600	−3.1%
	base	41.6	136,000	–	461,800	–	878,400	–
	+20%	49.9	139,200	2.4%	473,800	2.6%	887,600	1.0%
Time to Adjust Willingness [month]	−20%	2.33	148,400	9.1%	456,100	−1.2%	871,200	−0.8%
	base	2.91	136,000	–	461,800	–	878,400	–
	+20%	3.49	127,800	−6.0%	454,400	−1.6%	871,900	−0.7%
Time to Adopt [month]	−20%	2.0	155,600	14.4%	517,000	12.0%	923,700	5.2%
	base	2.5	136,000	–	461,800	–	878,400	–
	+20%	3.0	120,500	−11.4%	407,000	−11.9%	825,900	−6.0%
Time Lag in Churn Rate [month]	base	1.01	136,000	–	461,800	–	878,400	–
	+20%	1.22	148,300	9.0%	482,100	4.4%	863,700	−1.7%
Desired Frequency [1/month]	−20%	5940	145,300	6.8%	486,800	5.4%	892,800	1.6%
	base	7420	136,000	–	461,800	–	878,400	–
	+20%	8900	129,400	−4.9%	444,600	−3.7%	839,700	−4.4%
Elasticity of Frequency on CR	−20%	1.77	129,300	−4.9%	445,900	−3.4%	851,800	−3.0%
	base	2.21	136,000	–	461,800	–	878,400	–
	+20%	2.66	142,900	5.1%	485,100	5.0%	882,600	0.5%
LF Sensitivity on Price	−20%	0.11	136,000	0.0%	470,200	1.8%	917,700	4.5%
	base	0.14	136,000	–	461,800	–	878,400	–
	+20%	0.16	136,000	0.0%	453,100	−1.9%	837,000	−4.7%

・**Sensitivity of Advertising Effectiveness**

Fig. 8-16 shows the number of HSR adopters (top graph) and adoptions from advertising (AA) (bottom graph). Sensitivity of Advertising Effectiveness (AE) is considerable especially in the first several years after operation starts in terms of percent change (-11.4% to + 9.6% in 2025). The peak of AA is larger and comes faster in the case of greater AE. During the penetration phase, when the HSR service starts to attract adopters and the number of them increases, the effect of advertising rapidly raises the number of adopters. On the other hand, in the long run, AA decreases due to the balancing feedback loop of market saturation. Therefore, the relative importance of AE decreases, even though the difference of AA remains for an entire time horizon. Therefore, we should monitor uncertainties in AE especially during the initial years of operation.

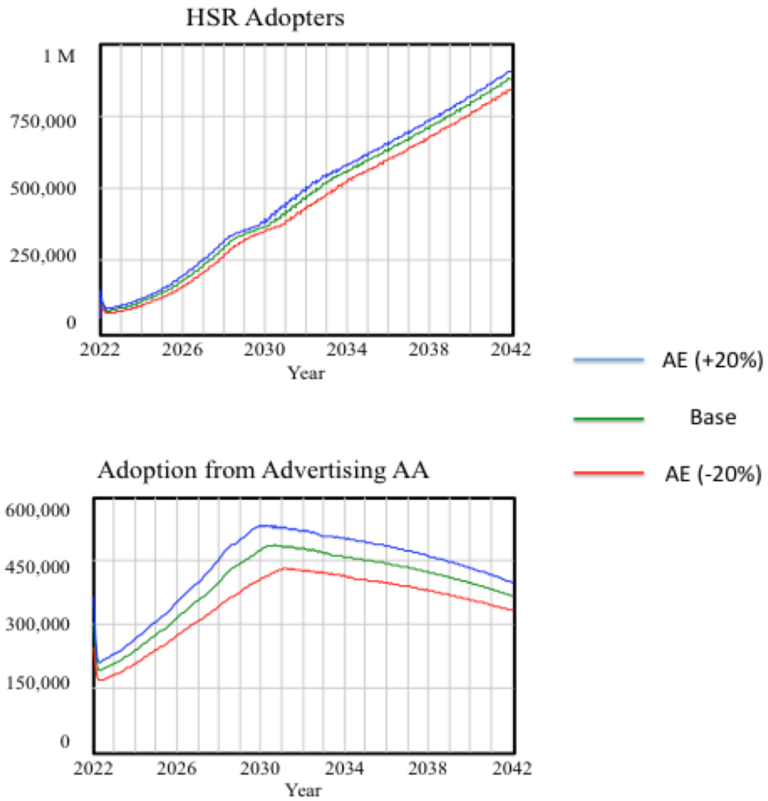


Fig.8- 16 The number of HSR adopters and adoptions from advertising [person/month] with different values of Advertising Effectiveness

・**Sensitivity of Adoption Fraction and Contact Rate**

Changes in Adoption Fraction (AF) and Contact Rate (C) cause the same results because word-of-mouth adoption is similarly affected by these two variables. The significance of sensitivity is less than 5% for the entire time horizon, so the system remains relatively robust in response to the change in these parameters, which have an impact on the effectiveness of word of mouth.

・**Sensitivity of Time to Adjust Willingness**

Fig. 8-17 shows time variation of the number of HSR Adopters and Potential Adopters for the different values of Time to Adjust Willingness (TAW). TAW has a relatively large effect on ridership during the penetration phase (around 2025), but this effect becomes smaller in the long run (less than 1%, after 20 years). In the case of 20% less TAW, the number of HSR adopters is increasing faster than others. This is because the development of potential adopters is faster for the case of shorter time to adjust willingness, and thus the adoption rate increases due to the large number of potential adopters. However, this difference begins to decrease around 2030, when the number of potential adopters reaches its peak. After around 2030, there is no significant difference among the three cases in terms of the HSR adopters. Therefore, we should monitor uncertainties in TAW especially during the initial years of operation.

・**Sensitivity of Time to Adopt**

The change in Time to Adopt (TA) has direct impact on ridership growth. As shown in Table 8-6, the sensitivity of TA is significant during the entire time horizon. Fig. 8-18 shows the ridership difference in cases with three different values of TA. The shorter the TA, which means Potential Adopters tend to adopt the HSR service quickly after the contacts with advertisement or word of mouth, the sooner the ridership grows. The three lines in the graph show the overall trend of similarly increasing rates, but a change in TA causes a 2-3 year time-delay in ridership development.

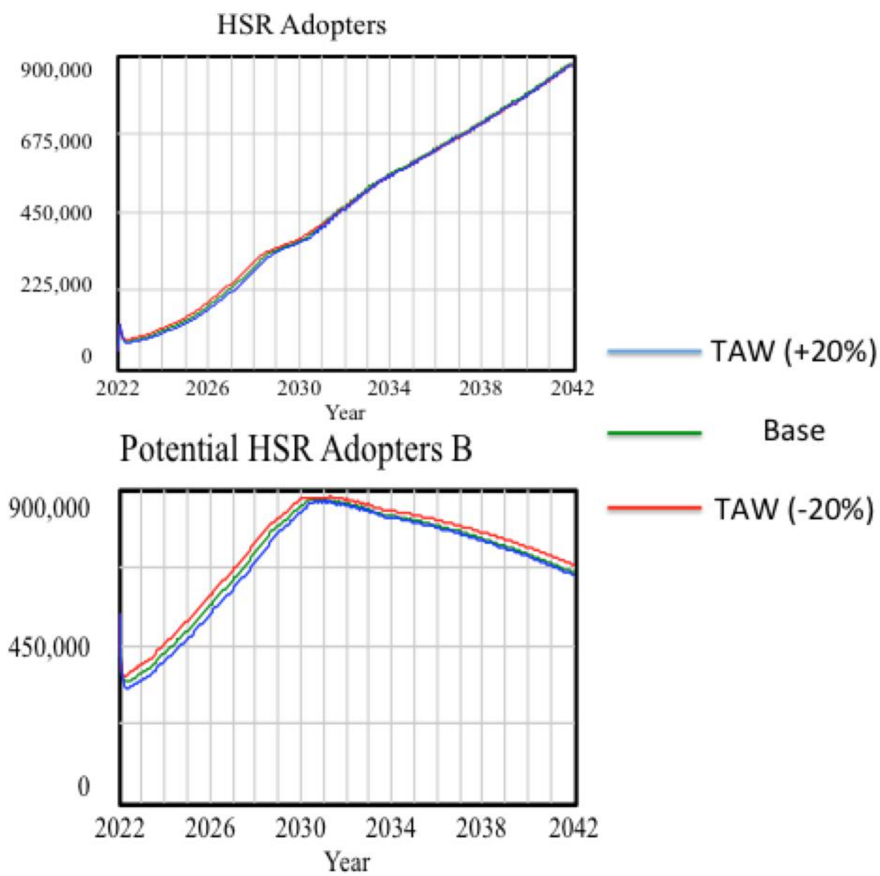


Fig.8- 17 Number of HSR Adopters and Potential Adopters [person/month] with different values of Time to Adjust Willingness

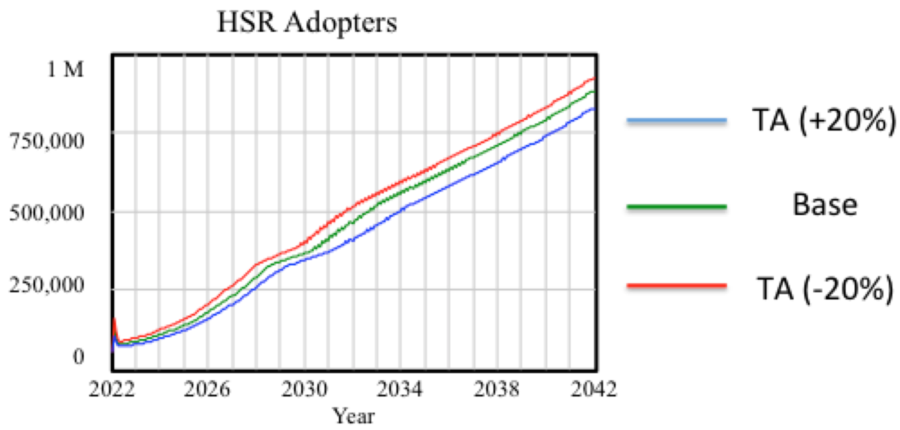


Fig.8- 18 Number of HSR Adopters [person /month] with different values of Time to Adopt

・**Sensitivity of Time lag in Churn Rate, Desired Frequency and Elasticity of Frequency**

Time lag in Churn Rate (TCR), Desired Frequency (DF) and Elasticity of Frequency on CR (EFCR) are relevant to churn rate in terms of operation frequency. Fig. 8-19, 8-20 and 8-21 show the number of HSR adopters with different values of TCR, DF and EFCR. Increases in TCR and EFCR, and a decrease in DF suppress the churn rate of HSR users. As a result, these changes result in higher ridership. As shown in Table 8-6, the sensitivity for this parameter is relatively large during the first several years of HSR's demand development phase. This is because operation frequency is increasing according to ridership and finally reaches the desired level. Therefore, the effect of these three input parameters on ridership decreases as frequency increases in the long run.

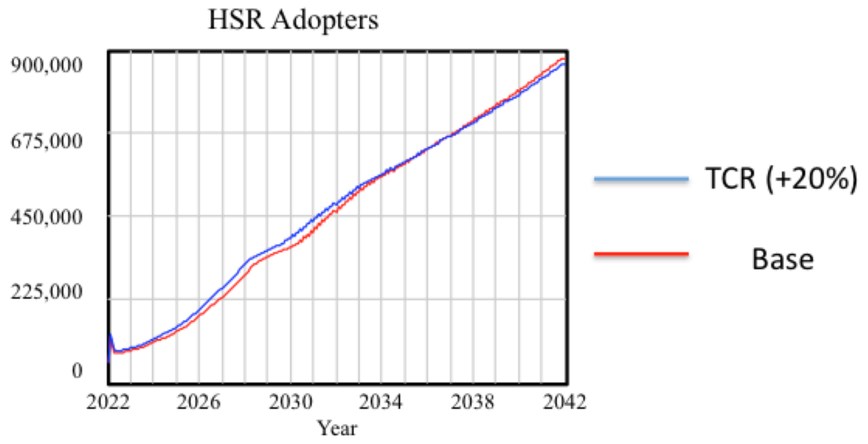


Fig.8- 19 Number of HSR adopters [person/month] with different values of Time lag in Churn Rate

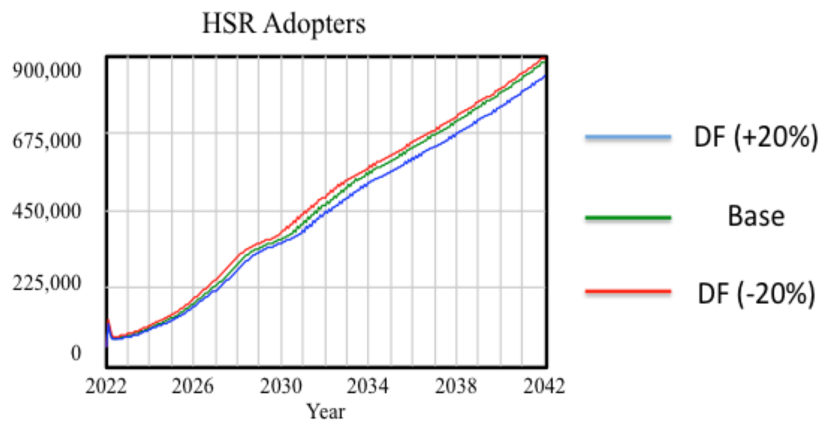


Fig.8- 20 Number of HSR adopters [person/month]with different values of Desired Frequency

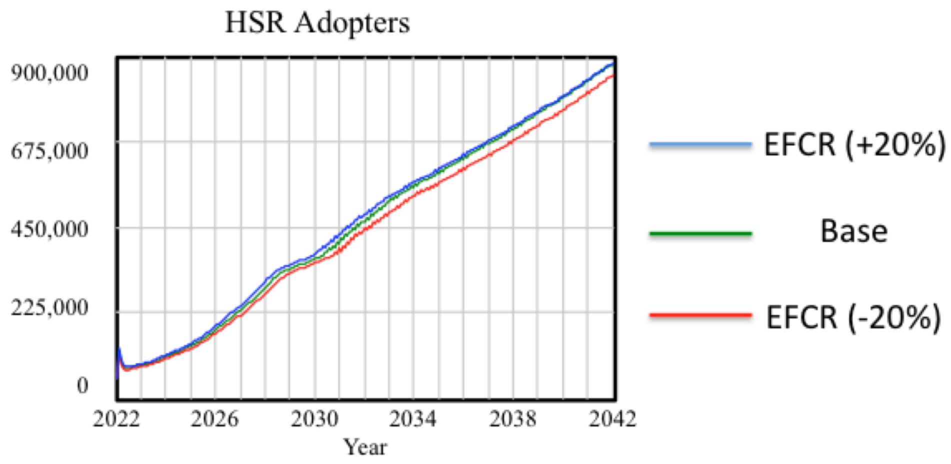


Fig.8- 21 Number of HSR adopters [person/month] with different values of Elasticity of Frequency on Churn Rate

・**Sensitivity of Load Factor Sensitivity on Price**

Increase in Load Factor Sensitivity on Price (LFSP) has a negative impact on ridership growth, because when LFSP is greater, the price increase rate according to the LF level is higher. As shown in Table 8-6, the overall sensitivity is not considerable for this parameter (less than 5%), but the sensitivity gets higher during the late years (after around 2030). Therefore, the ridership difference due to the uncertainties of this parameter emerges in the long run, as shown in Fig. 8-22. The HSR operator should take into account uncertainties in the parameter when considering the long time planning of the HSR operation.

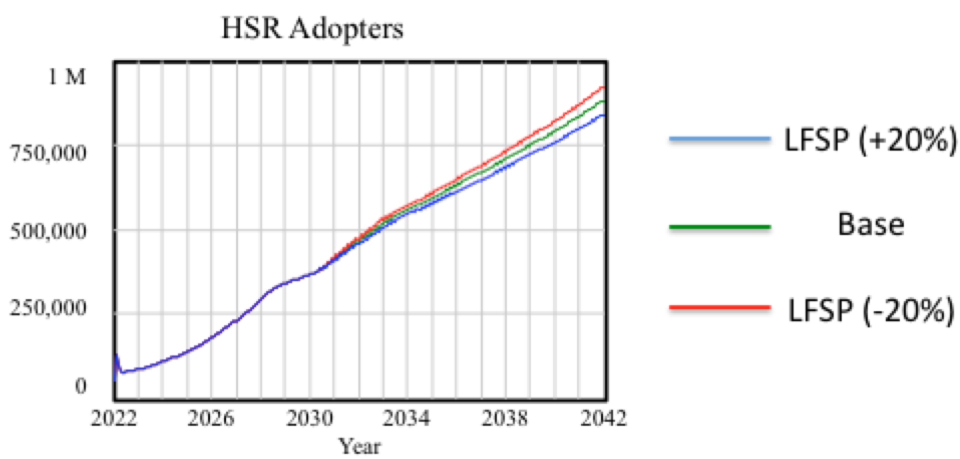


Fig.8- 22 Number of HSR adopters [person/month] with different values of Load Factor Sensitivity on Price

As a result, the plus/minus 20% change in each input parameter changes the results of the numerical simulation, but not significantly in the long run. This suggests that the model results are reliable from a long-term perspective even with some probable errors in these nine input parameters. The effect of changing largely one input parameter could occur the considerable difference in the short term, such as Advertising Effectiveness and Time to Adopt. But during the long period of time horizon, this volatility is absorbed in the other part of the model because the SD model we created has a complex structure and it includes several balancing loops.

8.6.2 Sensitivity Analyses for Policy Parameters

The purpose of the sensitivity analyses of this section is to see how each independent variable relevant to the managerial decision (policy) of the HSR operator affects the performance of the entire system in terms of ridership and revenue growth. These policy parameters are Initial Seat Price, Time to Increase Price (in pricing subpart), Time Required to Increase Frequency, Desired Load Factor (in capacity subpart), and Target Public Transportation Fraction (in accessibility subpart). The cost estimation is out of the scope of this research, so it is difficult to judge the financial feasibility of each decision. However, by changing these variables in this model, we can find out good strategies to improve overall performance of the Texas HSR system. The simulation is conducted based on the estimated values of input parameters in Table 8-3. In addition, we use the following assumptions for the calculation in this section:

In the Adoption part,

・Total intercity passengers are growing 1.89% annually [88]

・Total travel time of a car user is increasing 4.3 minutes annually, starting at 4 hours in 2022 and finally reaching 5.5 hours in 2042 [38].

・Total Population growth in the two regions is 1.5% annually.

・Reference price of the highway users is $35 (main competitor of the HSR).

In the Accessibility subpart,

・Time lag in changing utility of Public Car and Public Transportation is set at 12 months. This is based on the assumption that even if quality of the public transportation access is improved, it takes some time for the passengers to give up the private car use and adopt the public transportation to access the HSR stations.

・We consider the access (and egress) time to the HSR stations by assuming that the origins and destinations of the HSR passengers are both city's business districts in downtown areas. Based on this assumption, Initial Access Time of Private Car (without any delay by congestion around station) is set at 30 minutes. This is the sum of average driving time in the two cities (an estimated time is 15-20 minutes in Houston and 8-10 minutes in Dallas). Similarly, Access Time to Stations by Public Transportation is set at a constant 45 minutes (an estimated time is 30 minutes in Houston by existing bus service, and 15 minutes in Dallas by existing light rail service). We assume the travel starts when the passenger get on his/her private car, taxi, bus or light rail; therefore the access time does not include the walking time to private parking, waiting time for the taxi, waiting time at the bus stop or light rail station.

Table 8-7 shows the numerical condition of each simulation case. As the base case, we assume that the initial ticket price is set at $100 and increasing without time delay as the LF reaches the desired level, 70%. This price will be competitive with the airfare between the two regions, as the operator claimed even though the price has not been publicized yet [38]. We assume capacity increase in the base case is realized quickly (within 1 month) to sufficiently suppress the higher-than-desired LF. The proportion of public transportation users to access the HSR stations is initially set at 25%, which is the expected value in reality [31]. Starting from these base assumptions, the five policy parameters are changed one by one, and the results are compared with that of the base case to identify how each policy changes the system performance.

Table 8- 7 Conditions of numerical simulations

	Pricing		Capacity		Accessibility
case	Initial Seat Price [$]	Time lag in Changing Price [month]	Time required to increase Frequency [month]	Desired Load Factor	Target Public Transportation Fraction
base	100	1	1	70%	25%
Initial Pricing	90, 110	1	1	70%	25%
Price Increasing	100	2, 6	1	70%	25%
Frequency Increase	100	1	3, 6	70%	25%
Desired Load Factor	100	1	1	50%, 90%	25%
Accessibility	100	1	1	70%	35%, 50%

・**Initial Pricing**

As the first case, we conduct the analysis for the initial pricing of the HSR seat. The initial price in the base case is $100, and we change it to $90 and $110. Fig. 8-23 shows the simulation results of the three cases. First of all, ridership growth during the first 5 years of the cheaper price case (red line) is much larger than that of the base case (blue line) and the more expensive price case (green line). In the case of the cheaper initial price, the drastic increase in ridership occurs due to the high willingness to adopt, which is the function of price and travel time. The cheaper initial ticket price attracts a broader range of intercity passengers, including not only business users but also personal travelers, who have relatively low VOT. The adoption of HSR in the first phase is mainly caused by the advertising, so the high adoption rate of the cheaper price case is due to the large Adoption from Advertising. This effect does not last in the long run and the ridership and revenue growth is saturated after several years, because of the balancing loop of Market Saturation. (The ticket price is converging to almost the same value as a function of the load factor)

The load factors of the three cases are all converged to the desired level (70%) with certain delay of time. There are two balancing loops to manage load factor: Price Increase balancing loop and Load Factor Management balancing loop. In these three cases, both ticket price and frequency are increased to manage the load factor to the desired 70%. When the initial ticket is set at a low price for the HSR to penetrate into the market quickly, the frequency increase necessary to suppress the load factor to the desired level is large. Therefore, if the HSR operator wants to penetrate into the market by setting the initial price relatively low, then it is also necessary for the operator to increase frequency sooner to manage load factor and avoid the low service availability. Taiwan HSR operator seemed to take this combined strategy for the initial several years to penetrate into the market and develop the ridership demand quickly after its inauguration [104]. However, increasing frequency requires high operation cost and capital cost increase. The operator, who is likely to have difficulty in funding especially during the first several years, should balance the cost and revenue growth if the operator decides to take this penetration strategy.

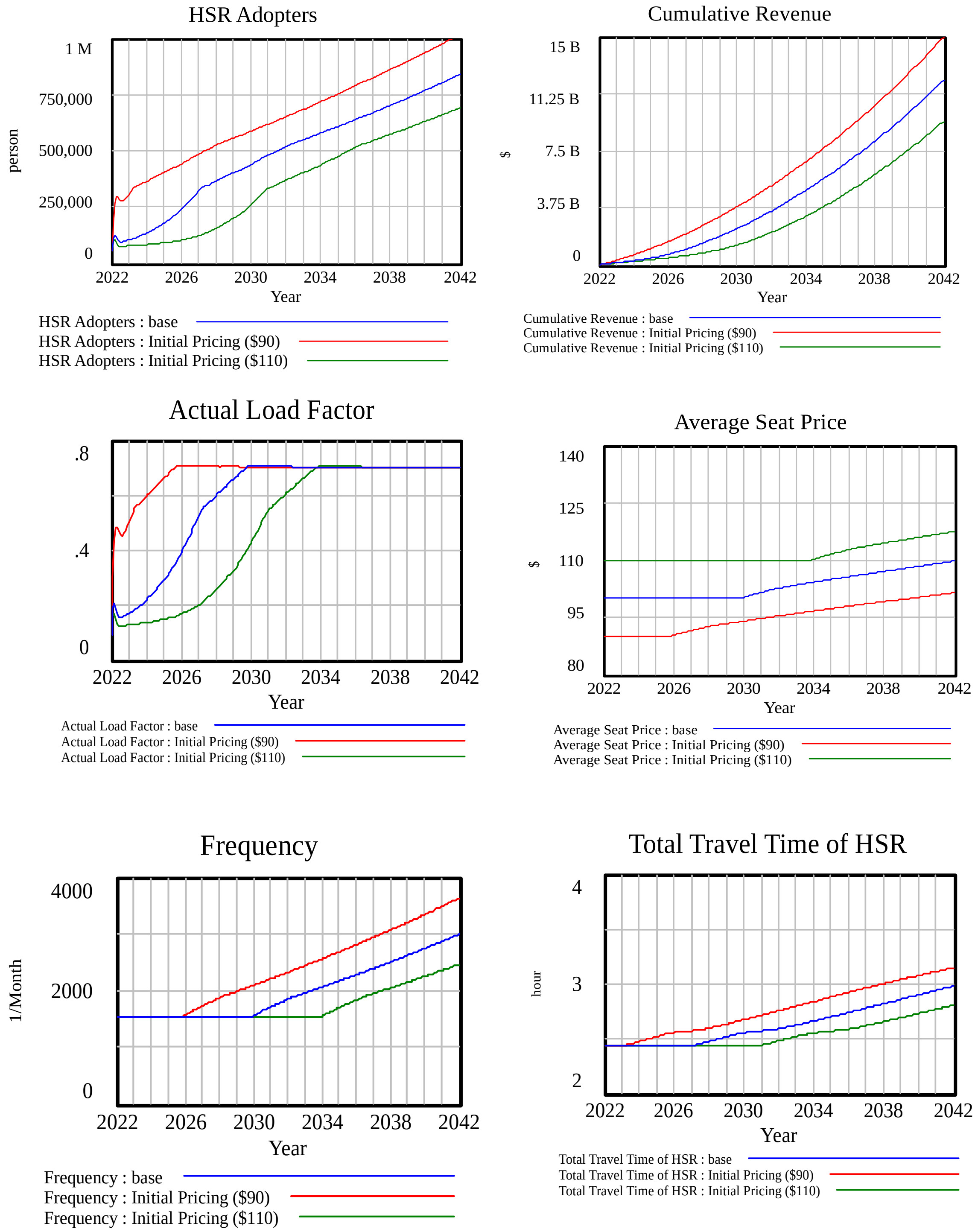


Fig.8- 23 Simulation results for different initial ticket price cases

(Initial Ticket Price = $90, $100 (base) and $110)

・**Price Increasing**

Fig. 8-24 shows the simulation results of cases in which we input three different values of Time lag in Changing Price (1 (base), 2 and 6 months). The smaller the time lag, the sooner the ticket price increases to the indicated price, as discussed in Section 8.4.2. The ridership graph shows that the smaller price increase results in the higher ridership growth and the slightly higher cumulative revenue, even though the unit ticket price is cheaper. This result shows that the price increase has a negative impact on the ridership growth, and consequently the increase in price cannot compensate for the decrease in ridership in terms of the cumulative revenue.

However these results could be interpreted in a different way in terms of load factor management. As mentioned in the previous discussion of the Initial Pricing, there are two ways to manage the LF: increasing frequency to supply available seats or increasing price to suppress the ridership. An increase in price starts when the actual load factor hits the desired level (70%), and at the same time the increase in frequency also starts to keep the LF to the desired level. As the frequency graph shows, when the price increase rate is smaller, then the operator has to increase train frequency more to manage the load factor and keep the high level of service availability. This leads to the increase in operation and capital cost to purchase additional rolling stocks and equipment. Of course, it is desirable to secure high ridership growth by suppressing the price increase rate and increasing frequency rapidly, which are the consequence of the balancing loop of Price Increase and the reinforcing loops relevant to the frequency increase (High Frequency Convenience and the Decreasing Wait Time). However, the balance between the revenue growth and cost increase of capacity expansion should be taken into account, which is out of the scope of this model.

In conclusion, pricing strategy could be one way to manage the load factor to the desired level. Although ridership growth is enhanced by keeping the price low and increasing frequency largely to keep the load factor at the desired level, this strategy needs more operation and capital cost to realize the desirable standard of load factor management. Therefore, the operator should decide the price increase considering the limitation of the capacity expansion of increasing frequency of the train operation.

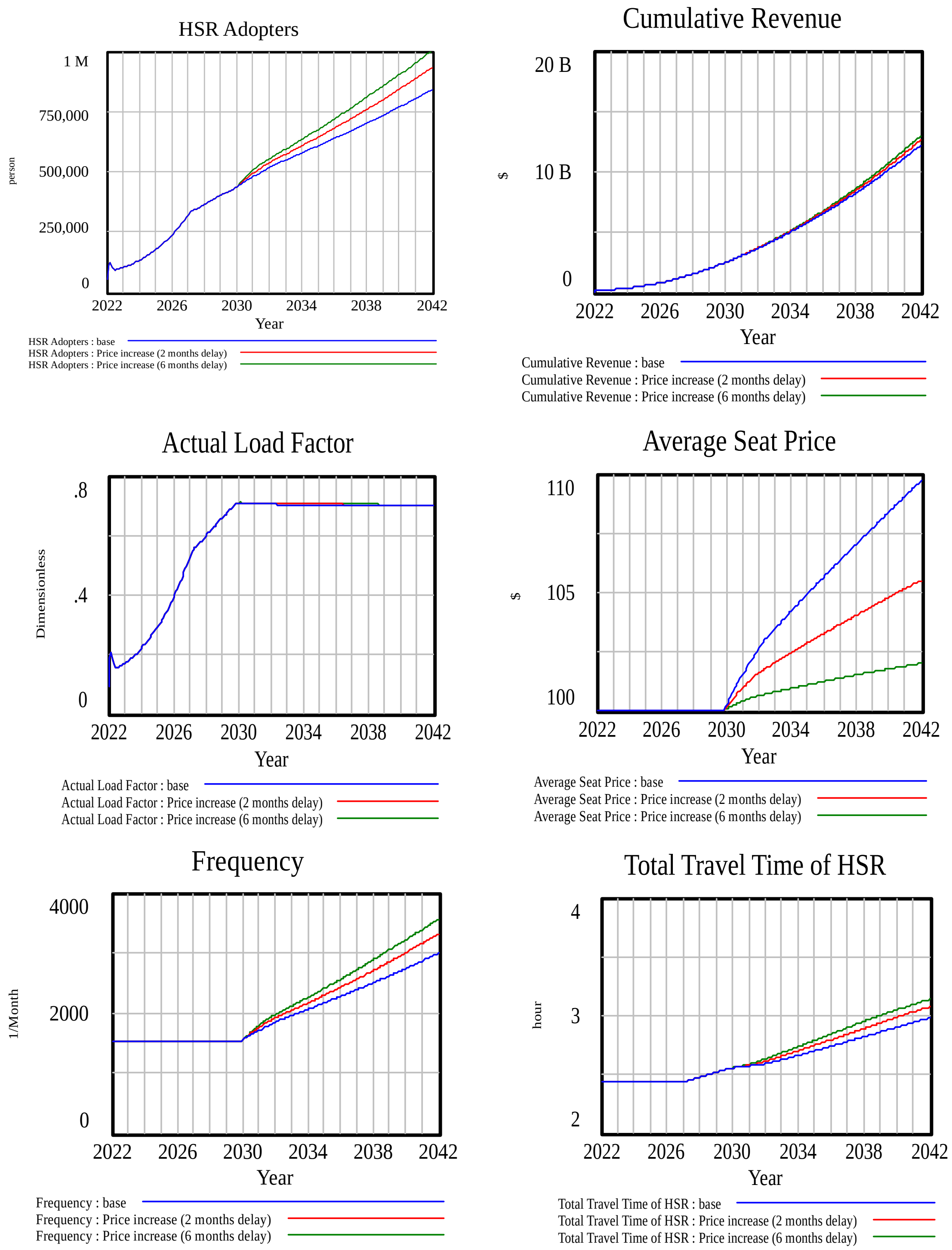


Fig.8- 24 Simulation results for different price increase

(Time lag in changing price [month] = 1 (base), 2, 6)

・**Frequency Increase**

Next, we conduct the sensitivity analysis relating with the capacity subpart. Fig. 8-25 shows the simulation results of cases in which we input three different values of Time Required to Increase Frequency (1 (base), 3 and 6 months). The shorter the time to increase capacity, the more quickly the frequency can be increased. To supply the sufficient number of seats to keep the load factor below the desired level (70%), it is desirable to increase frequency as quickly as possible, as discussed in Section 8.4.3.

The results show that the higher increase rate in frequency yields better ridership and revenue (although, as mentioned elsewhere, costs are not considered). The difference emerges after the load factor reaches the desired level around 2030. We should note that the load factor is similarly managed for three cases because the higher price increase could compensate for the slower frequency increase in the case of 6-month time lag (green line). When the frequency increase is rapid, then the price increase needed to manage the load factor can be small; therefore the rapid frequency increase can enhance the ridership growth further, because the reinforcing feedback loops relevant to frequency increase (High Frequency Convenience and Decreasing Wait Time) work more strongly, and the balancing loop of Price Increase works more weakly. This result is consistent with the characteristics analysis of HSR in Chapter 5, concluding that high frequency and capacity is the key advantage of the HSR system to compete with the other transportation modes. Of course, on the other hand, higher frequency requires higher operation and investment cost; thus we could not judge the feasibility of the strategy that the capacity should be expanded as soon as possible by increasing frequency. It is necessary for the train operator to combine the price and capacity increase strategies to realize stable ridership growth while restraining operating cost.

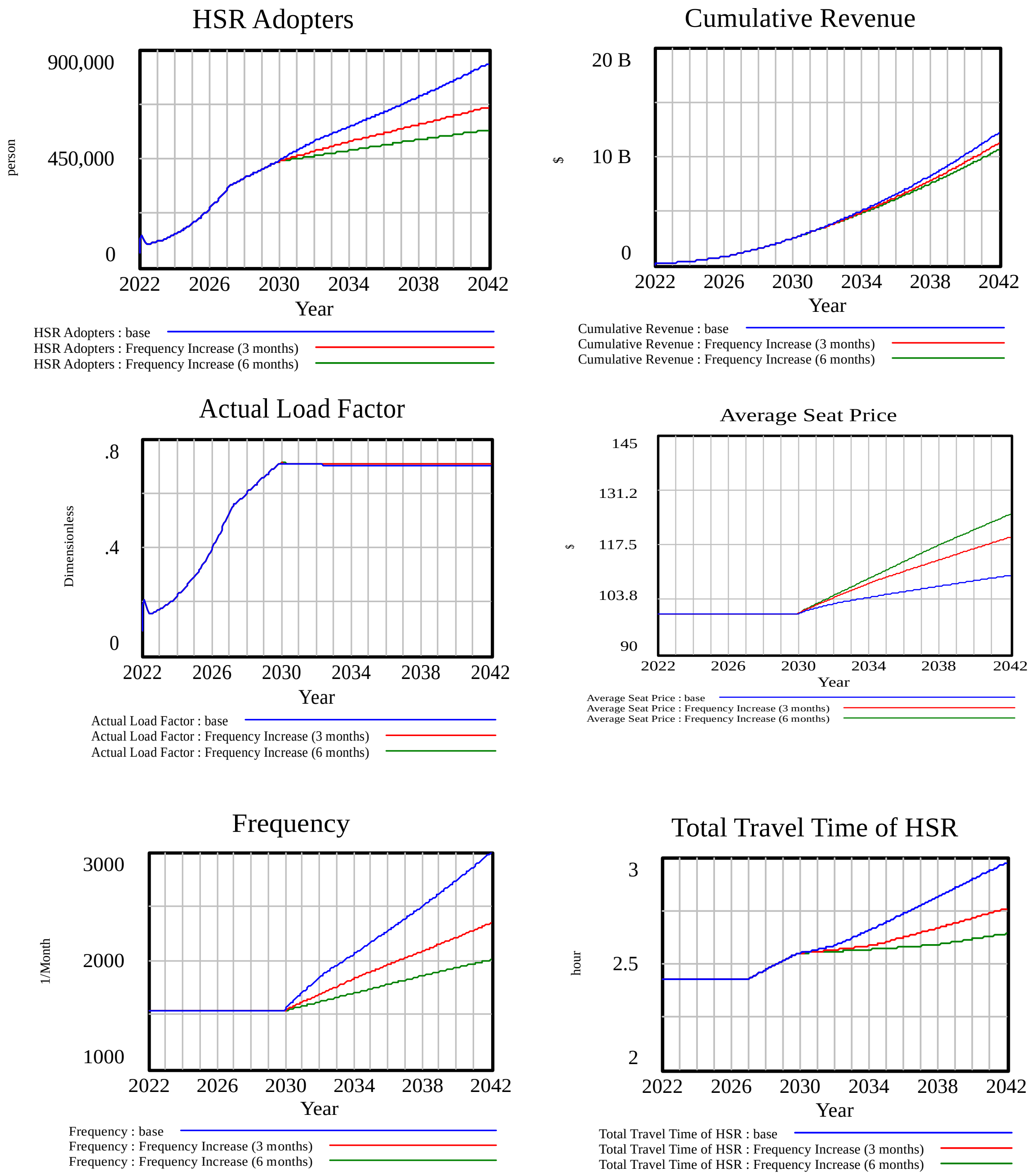


Fig.8- 25 Simulation results for different frequency increase

(Time Required to Increase Frequency [month] = 1 (base), 3, 6)

・**Desired Load Factor**

Fig. 8-26 shows the simulation results of cases in which we input three different values of Desired Load Factor (50%, 70% (base) and 90%). By increasing frequency and the ticket price, the actual load factor is adjusted to the desired levels. We should note that the smaller the LF, the better the Service Availability, which creates the balancing feedback loop as discussed in Section 8.2.5. If the Desired LF is set at too high value (such as 90% as shown in green line), then the balancing loop of the Service Availability works strongly. Consequently, the ridership growth is impeded in this case.

The graph of cumulative revenue shows that the revenue is almost the same for the base case (the Desired LF = 70%) and the case of lower Desired LF (50%). From the viewpoint of Service Availability, keeping the LF to lower value does not seem a bad strategy. However, to keep the lower Desired LF, it is necessary to increase frequency in an early stage of the demand development phase. Therefore, in terms of cost increase due to the frequency increase, it is not desirable to keep the LF too low.

We should note that the desired level of load factor could be lower than the results this model indicates, because there are several advantages for the HSR users to have the less occupied trains (for example, they can select an aisle or window seat according to their preference). However, the load factor is an important indicator for the HSR operator to see the utilization of assets. Therefore, the Desired LF should be set at the appropriate level considering the balance of service availability and relevant cost of keeping LF low.

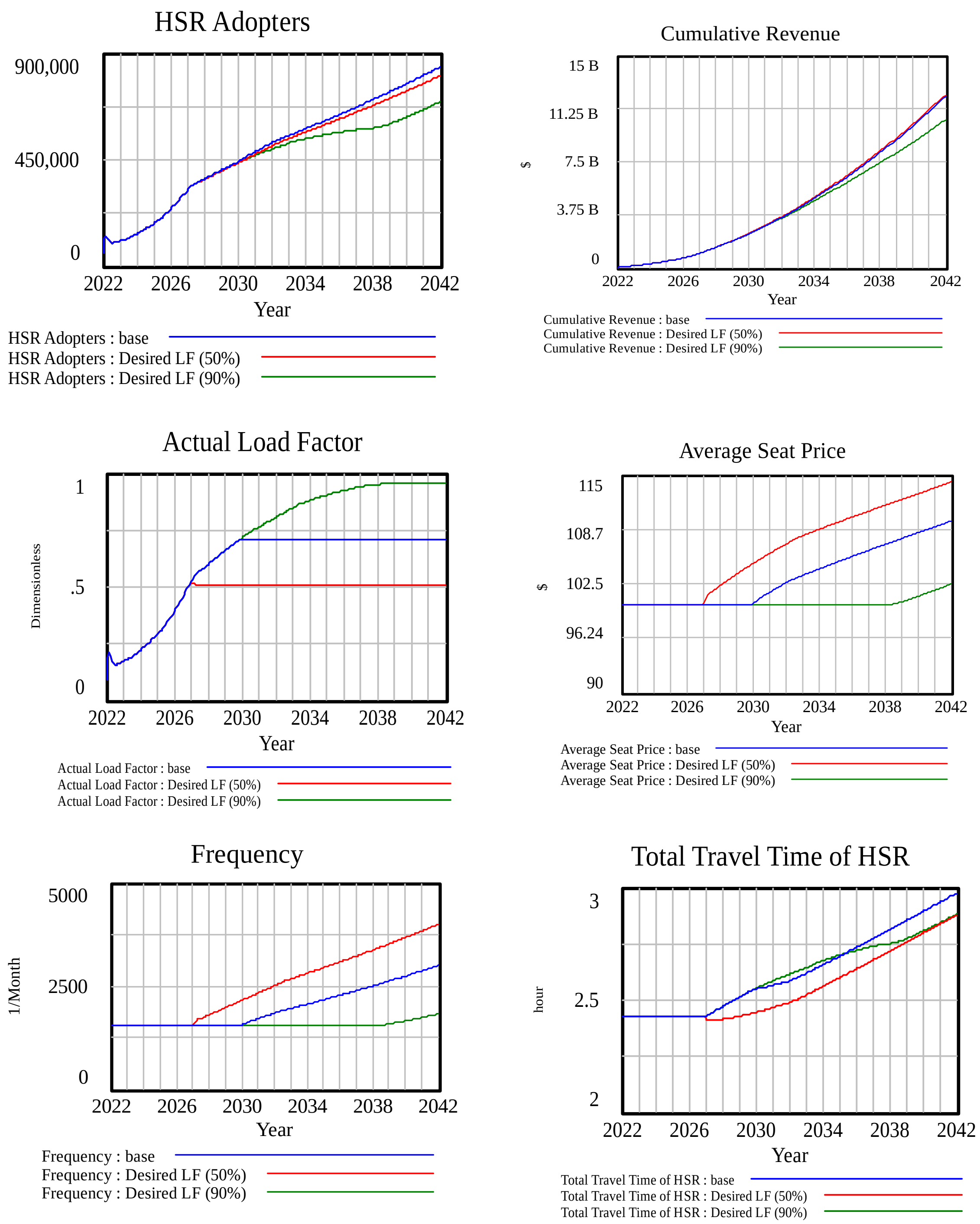


Fig.8- 26 Simulation results for different desired load factor

(Desired Load Factor = 50%, 70% (base), 90%)

・**Accessibility (Target Public Transportation Fraction)**

Finally, we conduct the sensitivity analysis relating with the accessibility subpart. Fig. 8-27 shows the simulation results of cases in which we input three different values of Target Public Transportation Fraction (25%, 35% and 50%). The higher target fraction means more HSR adopters access (or egress) the HSR stations by public transportation and less of them use car. The increase in ridership in the three cases is enhanced by the increasing frequency. If the public transportation utility rate is low, high growth of ridership causes the congestion around the HSR stations; thus the total travel time of the HSR users increases after the traffic volume reaches the road capacity and parking facility limitation (around 2028 in the graph). This congestion impedes the further ridership growth due to the low willingness to adopt, which is the function of price and total travel time. When the target proportion of public transportation users is set at a high level, the road and parking congestion are mitigated and the average access time to station does not increase so much even after the traffic volume reaches the capacity limitation of the car-related facilities.

This result shows that the access to the HSR stations by the sufficient capacity of public transportation (mass transit system, light rail system, bus network, etc.) is the important factor to keep the HSR's advantage of ease of access from the city center. In Texas, due to the high rate of car ownership, it is predicted that people access the HSR stations mainly by the private car. However, there are limits to how much car traffic and parking can be accommodated around the HSR stations. In conclusion, improving the quality of the public transportation network is crucial to induce more public transportation users, and consequently the improved public transportation network enhances the competitiveness of the HSR with the other modes. Therefore, cooperation between the private HSR operator with the public sector transportation providers is vital to provide good accessibility to the HSR stations.

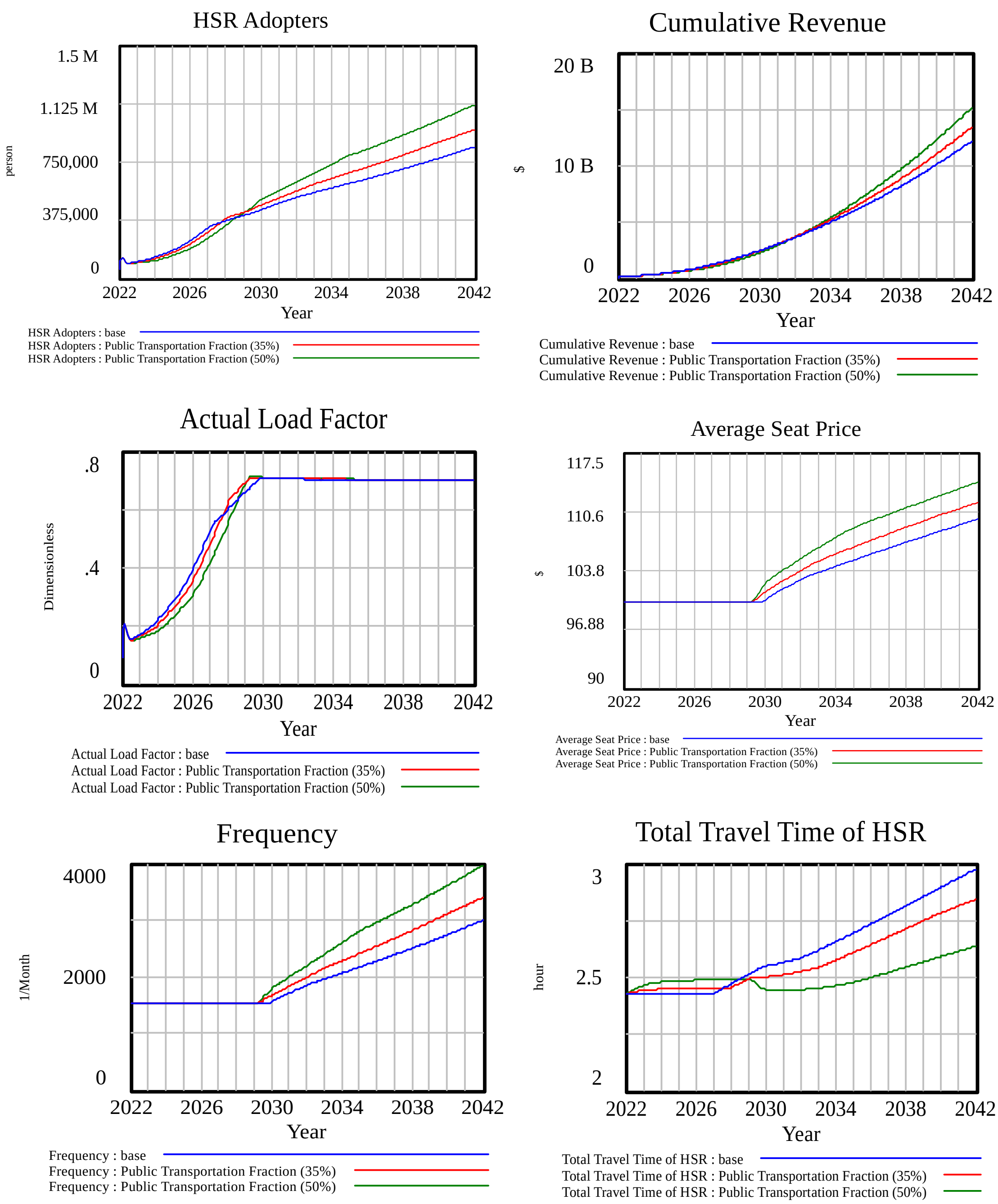


Fig.8- 27 Simulation results for different desired load factor

(Target Public Transportation Fraction = 25% (base), 35%, 50%)

8.7 Conclusions from Quantitative Analysis Using System Dynamics Approach

In this chapter, the System Dynamics approach is introduced as the third "Ornament" of the CLIOS Process [4] to evaluate the several bundles of strategic alternatives over time. The key findings of the qualitative analysis of the CLD, discussed in Section 8.3, is the basis to conduct the numerical simulation. In Section 8.4, the numerical SD model is created based on the Bass Diffusion Model concept. The basic idea is to attract potential customers to the new HSR system from other transportation modes through advertising and word-of-mouth. The main competitor is assumed to be highway users, so passenger's willingness to adopt HSR service depends on the difference of total travel time and travel cost between car and HSR users. Three subparts of the numerical model, which are relevant to the strategic alternatives- pricing, capacity and accessibility - are connected to the main adoption part to represent complex causal relationships of each component to the system performance.

First, the SD model is applied to the Taiwan HSR market to estimate several input parameters in order to check whether the model could capture overall market trends. These input parameters are relevant to the strengths of advertising and word-of-mouth, time lags to change willingness to adopt or stop to use HSR, and the effect of frequency on the churn rate of HSR users. We conduct a statistical method of fitting simulation results to actual data, and find out the estimated value for each input parameter. The result shows that the overall trends of ridership development are well captured in the numerical model with appropriate values of the estimated parameters. As confirmed by this model calibration, the SD model can capture this HSR system's structure and trend well.

Then, we apply the same model with the estimated parameters to the Texas HSR case. Firstly in Section 8.6.1, sensitivity analysis of the estimated parameters on ridership growth is conducted to check the robustness of the model with regard to probable uncertainties in each estimated value. The uncertainty in two parameters, Advertising Effectiveness and Time to Adopt, has a considerable impact on ridership especially during the short time horizon. These results suggest that ridership growth during the initial several years is affected strongly by the strength of advertising and the time lag in passenger's perception. Therefore, the HSR operator should take into account these advertising-related uncertainties especially during the market-penetration phase. However, the sensitivity of these variables tends to taper off, because the advertising does not have lasting effect in the long run (this is due to a balancing feedback loop of market saturation, as discussed in the previous section). On the other hand, the other result suggests that sensitivity of load factor on ticket price increase has a negative (but not large) impact on ridership in terms of decreasing willingness-to-adopt, and this effect gets stronger after the LF reaches the desired level during the late years. Although the impact is moderate, the HSR operator had better monitor the actual LF and its influence on price increase, especially during the demand expansion and market domination phase (as described in Chapter 6). While we find out these uncertainties in the input parameters have a certain impact on ridership, the result of sensitivity analysis suggests that the numerical model we create robustly predicts the long-term future performance of the HSR system in Texas.

Finally, as discussed in Section 8.6.2, we conduct the sensitivity analyses of policy parameters, which are implemented in the model based on three strategic alternatives: pricing, capacity management, and accessibility management. The purpose is to see how managerial decision of the HSR operator affects the system performance in terms of ridership and revenue growth. The results of the numerical simulation suggest the following conclusion:

・Initial-pricing strategy has a direct impact on ridership growth during the initial several years (a penetration phase), in terms of potential riders' "willingness to adopt." Low initial price induces a high rate of adoption mainly through effective advertising. However, the sharp initial growth of ridership requires the intense increase in operation frequency in order to keep a high level of service availability (in other words, average load factor is managed below the desired level). Thus, low initial price setting could result in high adoption rate only if the train frequency is sufficiently increased according to the ridership growth (as shown in Fig. 8-24). The frequency increase needs a large investment cost in rolling stock and other equipment for the operator, so the cost and revenue growth should be balanced if the operator decides to take this low-initial-price policy as its penetration strategy (the cost estimation is out of the scope of this research, though).

・To realize stable growth during a demand expansion phase, it is necessary to manage average load factor and service availability to a certain level with capacity management strategies. The operator could manage load factor by increasing frequency to supply sufficient seats and increasing price to restrain ridership. It goes without saying that it is more preferable to induce ridership by avoiding the price increase and supplying satisfactory amount of seats by increasing frequency. However, the balance between the revenue growth and cost increase of capacity expansion should be taken into account from the viewpoint of the operator's financial viability. Therefore, load factor should be controlled at an appropriate level based on a long-term perspective, by the well-balanced combination of increasing frequency and price to control both supply and demand side of the system.

・Accessibility management is the key factor for long-term stable growth of HSR ridership in terms of total travel time saving. The utility rate of the public transportation to access the HSR stations is an important indicator. If the public transportation utility rate keeps low, growing ridership causes the congestion around the HSR stations, and the total travel time increases after the traffic volume excesses the capacity of road and parking facility. This congestion hinders the long-term ridership due to the decreasing timesaving of HSR users compared with highway users. Therefore, the private operator should take action to cooperate with the public sector to increase utilization of the public transportation to keep high retention rate, especially before and during a market domination phase.

In the next chapter, we propose several recommendations to the private operator based on the above key findings. The conclusions of this research, and possible future steps for further investigation are also shown.

Chapter 9: Concluding Comments

9.1 Summary

The purpose of this thesis was to find out what are the characteristics of the Texas HSR project, which is driven by the private sector; what are the strengths of a HSR system to serve as a form of intercity transportation; and what competitive strategies affect the HSR ridership and profitability in Texas? This research will show the possibility of the HSR system to change the transportation in the US and basic understandings of what strategies can make the private project successful. The additional purpose is to clarify the role that HSR should take in the future intercity transportation systems in the US, and to make some recommendations for the HSR operator.

In Chapter 2, we summarized the overall situation for several HSR projects in the US as a background to start the discussion. Based on the conflicts of political parties and activists, there have been pros and cons for HSR projects all over the US. These conflicts have made the progressions slow, or even worse, some publicly funded projects were stopped by governmental interventions, questioning the projects' economic viabilities. To break the deadlock, new movements have occurred in the private sectors.

The Texas HSR project is one of those private projects, and the overall outline of the project was briefly explained in Chapter 3. The Texas HSR project connecting Houston and Dallas using Japanese technology is totally unprecedented. Because not only is it a fully private HSR project, but also it will be constructed in a highly car-centric society, this project has many challenges and uncertainties from the beginning of its construction to after the commencement of service. This information showed us that the success of the project depends on various and complex factors, and these factors may lead to unforeseeable consequences in its future. This is the reason why we chose the CLIOS Process, which has been applied to various planned HSR analyses, including the Northeast Corridor [55], the California HSR project [148], the Singapore and Kuala Lumpur Line in Malaysia [113], and so forth. The CLIOS Process is useful to answer those questions, "What can the HSR provide as a "public good?" "Can profitability of the project be a public good for Texas and the US?" and "What can HSR do in the car-oriented society?"

Then in Chapter 4, as the framework for structuring the Texas HSR project, we used **the representation stage of the CLIOS Process**. Due to the "complex, large-scale, interconnected, open and sociotechnical" characteristics of the Texas HSR project [4], it was a critical step to visualize the overall structure of the project from the political, economic and sociotechnical viewpoints. To grasp the overall structure, five subsystems in the Physical Domain and the Institutional Sphere were clarified. Then, information gained from these descriptions was used for the prescriptive treatment of the system, by identifying the "high-impact network" inside the HSR system.

After the representation stage, **three "ornaments" were introduced** to design, evaluate and select the bundles of strategic alternatives for the Texas HSR project [4]. In Chapter 5, **the first "ornament," a comparative study of the HSR characteristics**, was introduced to identify what are the strengths of Japanese Shinkansen technology, compared with a general HSR technology and other transportation modes. This analysis was mainly conducted in terms of HSR's technical features based on literature reviews. The ideal "design" of the Texas HSR system was identified in this chapter.

To realize stable ridership growth and to make the project profitable, it is important to understand the market conditions in Texas to highly utilize the HSR's strengths, which were discussed in Chapter 5. Thus, in Chapter 6, we applied **the "strategic triangle" of the 3 Cs model [5] as the second "ornament"** to analyze the market conditions from the viewpoints of Customer, Corporation, and Competitor. This qualitative analysis showed us how the HSR operator could reinforce the advantages of the system to compete with the other modes in the passenger market between Dallas and Houston. Three strategic alternatives, pricing strategy, capacity management, and accessibility management, were proposed as the "Key Factors for Success" of the HSR project [5].

As the last "ornament," we applied the System Dynamics approach [137]. The SD model we create is based on the findings of the representation stage of the CLIOS Process and two previous "ornaments;" Pricing strategy, capacity management and accessibility management. First, we identified key feedback loops that determine the behaviors of the system from the Causal Loop Diagrams (CLDs) of the HSR system. Second, we structured its numerical model to conduct quantitative analysis of ridership, revenue growth and other variables. Finally, we identified an effective bundle of "strategic alternatives" over time, based on the three strategies in Chapter 6, for the private company to make stable growth.

As an overall conclusion of this thesis, several recommendations to improve the performance of the Texas HSR system will be proposed in this chapter. This section is considered to be a part of the Implementation stage of the CLIOS Process [4].

9.2 Key Findings

In this section, key findings gained from each Chapter are shown as follows:

Characteristics of the Texas HSR project (Chapter 2, 3 and 4)

・The slow progression of the HSR projects in the US has been caused mainly by the political and financial conflicts, due to its political system and public funding scheme. One of the new types of projects from the private sector is the Texas HSR project.

A huge infrastructure project across several states is hard to realize due to the difficulty of reaching public consensus over all those states, especially when it uses US government funding. To reach an agreement over the new construction of HSR among multiple stakeholders in broad regions is a politically difficult task. A US public funding scheme makes it much more difficult to happen. In terms of funding and political agreement, the Texas HSR makes the situation simpler because it will be privately financed and constructed only within one state.

・One of the most important features of the Texas HSR project is the fact that it will be privately financed. There is a tradeoff between two aspects: the freedom of actions, and uncertainties in land acquisition and fund raising.

To adopt a private finance scheme is effective to mitigate the political interference and to secure the freedom of managerial decision-makings for the operation entity to pursue its profitability. But these advantages are gained in exchange for the uncertainties in financial viability and land acquisition process.

・Profitability will reinforce the strengths of the HSR system, in terms of reinvestment in transportation infrastructure and service. This is a positive cycle of profitability and service improvement.

The sufficient operation revenue can induce further private investment, and it will be used for reinvestment and for service improvement. This enables the private operator to reinforce their competencies with other modes. This process strengthens the HSR's trip attributes, enhances the competitiveness, and therefore, the operation revenue increases as a result of high modal share of the HSR. This positive cycle is vital for the private operator to be profitable.

Competitive advantages of a general and the Japanese Shinkansen HSR system (Chapter 5)

・In general, the primary advantages of an HSR system shine when it connects two, or more, of the densely populated areas, which are located in middle distance away from each other.

From the several literature reviews, the advantages of the HSR are found to be its relatively high speed and high capacity, which can meet the high transportation demand between two or more of the large metropolitan areas 200-400 miles away. This advantage can be found not only in Japan, where the rail network is originally well developed, but also in Europe, where the new HSR lines changed drastically the modal share of the intercity passenger transportation, as shown in Fig. 5-3.

・Frequency, capacity, accessibility to the station, and safety are the competitive advantages with other modes.

HSR system can provide high capacity, high frequent transportation service that the other modes cannot provide. It can mitigate high burden on the existing transportation networks such as congested airports and highways. Good accessibility to the HSR stations from city centers is the competitive advantage of the HSR over flight. High standard of safety is the important competitive advantage of the HSR over highway.

・A Japanese Shinkansen system is suitable for high frequency operation due to its utilization of a dedicated corridor and its low energy consumption.

The Texas HSR project will be constructed based on the Japanese bullet train systems based on "Crash Avoidance Principles," [34] using a fully dedicated line for passenger service and ATC system that prevents crashes between trains. Dedicated track gives the operator more room for increasing the frequency than do the other HSR systems, which use shared rail with freight or conventional rail. In addition, it has no need to make the train cars robust; therefore it enables the rolling stocks to be lighter, and this makes the system energy efficient. These two features make the Japanese HSR system suitable for high frequency operation.

Market analysis based on the "Strategic Triangle" (Chapter 6) [5]

・The "Strategic Triangle" analysis has an advantage of focusing more on customer-based strategy than other frameworks of market analysis do. It is applicable to the transportation market analysis, too.

"The Strategic Triangle" is a framework for marketing research, considering the business strategy from the viewpoints of the 3Cs, Customer, Corporation and Competitor. This methodology is useful for the analysis of not only the commodity market, but also the inter-city transportation market, having fierce competition between the HSR and other modes. The focus is on what customers need and how we can segment those customers into several categories.

・Customer-based analysis: The segmentation of the potential customers should be based on their objectives for inter-city trip. Business users are the priority targets, and expanding to the other segments is the key to further growth. After entering the market, penetration speed and depth are important for the HSR to effectively dominate the market.

The potential customers in the market are segmented based on their objectives, which are the determinants of passengers' value of time, frequency needs, and desire for convenience of changing seats (this was also discussed in Chapter 4, in the section of the Institutional Sphere). Appropriate differentiation of the ticket is needed to capture the wide range of customers, as shown in Table 6-1. Marketing effort should be planned based on which segments of customers the HSR targets. Because the coverage of the transportation service is geographically limited along with the rail line, the HSR marketing should be conducted with "deep and narrow" marketing strategy to attract local people, especially business users who have high value of time.

・Corporate-based analysis: The main focus points that differentiate the HSR service from others are changing over time, based on its phases: penetration phase into the market, demand expansion phase to other segment of the market, and market domination phase.

If the HSR system has "a decisive edge" in one function of its operation, then this makes the system competitive over other competitors. The decisive edge should be changed depending on which strategic phase the system is in. Firstly, in the phase of penetration, sales price and strong promotion are the key factors to success. Next, in the phase of expansion to other segments in the market, the company should rapidly increase capacity of seats available, and should introduce price discrimination to attract other segments than business users. Finally, in the phase of market domination, maintaining the service quality to keep the good reputation and high retention rate of the customers is important for the continuing growth of the HSR ridership.

・Competitor-based analysis: The main competitors are private automobile and airline industries. To attract customers away from these competitors, accessibility to the HSR stations is the key factor to success.

More than 90% of the inter-city passengers use private automobile, which is strongly supported by the high rate of car ownership in Texas. The private auto is convenient because it provides door-to-door service. Other competitors, the airline industries, provide rapid transportation, but accessibility to the airports is the disadvantage. The HSR has to compete with them by providing good accessibility to the HSR stations from the city center.

・The “power of an image,” which is determined by reputation and marketing effort, is important especially in all of the three phases, penetration, expansion and market domination.

The key factor to success is to emphasize the functional differentiation of the HSR system by utilizing reputation, which is based on word of mouth, and the marketing effort (the Bass Diffusion Model of the System Dynamics in Chapter 8 is based on these results).

・We can learn useful lessons from the Taiwan HSR case, where pricing strategy, capacity management and accessibility to the HSR stations plays important role to increase ridership. Due to the many similarities between the Texas and Taiwan HSR, we assume that the basic behavior of the Taiwan HSR would have the same trends in the Texas HSR.

In terms of distance, utilization of Japanese HSR technology and its single link system between the two largest cities, the Taiwan HSR line is a good reference when considering the strategies for the Texas HSR project. It expanded the passenger market by gaining customers from flight and car industries. The main strategies are setting low-ticket prices for penetration, increasing frequency drastically, and securing accessibility to the stations from city centers. These are consistent with the basic findings from the previous section. The historical data of the Taiwan HSR was used to calibrate the basic structure of the SD model created in this research in Chapter 8.

Application of System Dynamics approach (Chapter 7 and 8)

・System Dynamics (SD) is a useful methodology to evaluate the dynamic behavior of the HSR system. It enables us to conduct quantitative analysis of each strategic alternative.

There are many application examples of the System Dynamics approach in the transportation field. The complex structure of the transportation system can be simply conceptualized by the method, especially two types of feedback structures: reinforcing loops and balancing loops. This research shows the possibility of SD application to the HSR operation as a part of the entire CLIOS Process. The information gained from the other parts of the CLIOS Process is reflected in the formulation of the SD model.

・This research is based on the assumption that the application of the Bass Diffusion Model to the HSR is useful to conceptualize the diffusion of the new transportation system, to visualize the feedback structures, and to capture the trends of the system behaviors.

The basic structure of the Bass Diffusion Model, which represents the market penetration of new products, is based on customers' adoption from the advertisement and word of mouth. In this research, we assume that this structure is applicable to the trends of the HSR adopters. People's behavior does not change quickly in terms of adaptation to the new transportation modes. Even after the income level (therefore, value of time) reaches the sufficient level to adopt expensive HSR tickets, it may take years for people to recognize the service quality and to actually adopt it. Our research is based on the assumption that the Bass Diffusion Model can capture this trend well.

・The holistic model structure created by integrating several subparts of CLDs clarifies the importance of load factor as a key indicator of ridership growth. It is relevant to several feedback loops and has a strong influence on the growth of the HSR adopters.

There are three CLD subparts, representing pricing strategy, capacity management and accessibility management to the HSR stations from the viewpoint of the HSR operator. When all of these subparts are integrated with the basic structure of the Bass Diffusion Model, as shown in Fig. 8-6, several feedback loops emerge. The balancing loops of Price Increase, Service Availability, Load Factor Management, and the reinforcing loop of High Frequency Convenience are directly relevant to load factor, which are key considerations of pricing strategy and capacity management.

・The basic structure of the SD model we created is applicable to the Taiwan HSR case, because the simulation results correspond reasonably well with the historical data in Taiwan. We assume that the SD model is also applicable to the Texas HSR because of many similarities between the two HSR projects.

The SD model we created is primarily for the analysis of the Texas HSR. Because there is no available data that can be used for the model calibration in the Texas HSR case, we conducted the simulation for training. The results of this simulation were compared with the historical data of ridership, modal share and frequency in the Taiwan HSR case between Taipei and Kaohsiung. Overall trends in the data of the Taiwan HSR fit relatively well to the behavior in the SD model. Therefore, we concluded that the SD model we created is applicable to the Taiwan HSR case. Because there are many similarities between the Taiwan and Texas HSR as discussed in Chapter 6, we assume that the SD model is also applicable to the Texas HSR case.

The key findings from the results of sensitivity analyses are as follows:

・Pricing strategy should be considered with capacity management in the penetration phase.

Initial pricing strategy has a direct impact on ridership growth during the initial several years. The sharp initial growth of ridership due to the low price setting requires the intense increase in operation frequency in order to keep a high level of service availability. Thus, low initial price setting could result in high adoption rate only if the train frequency is sufficiently increased according to the ridership growth. Therefore, cost and revenue growth should be balanced if the operator decides to take this low-initial-price policy as its penetration strategy.

・To realize stable growth during the demand expansion phase, it is necessary to manage average load factor by the well-balanced combination of capacity management and pricing strategy to control both supply and demand side of the system.

The operator could manage load factor by increasing frequency to supply sufficient seats and increasing price to restrain ridership. It is more preferable to induce ridership by avoiding the price increase and supplying more seats by increasing frequency. However, the balance between the revenue growth and cost increase of capacity expansion should be taken into account. Therefore, load factor should be controlled at an appropriate level based on a long-term perspective.

・Accessibility management is the key factor for long-term stable growth of HSR ridership.

The utility rate of the public transportation to access the HSR stations is an important indicator in terms of total travel time. Growing ridership causes the congestion around the HSR stations after the traffic volume exceeds the capacity of road and parking facilities. This congestion hinders the long-term ridership. Therefore, accessibility management in the early stage of the project is necessary to keep stable growth in the long run.

9.3 Recommendations

From the findings of the previous chapter, well-balanced strategies for pricing, capacity management and accessibility management are the key factors for success of the HSR operator. Even though we do not include the cost estimation in the model, we can suggest several recommendations for the sake of the HSR operator to be profitable.

Recommendation 1

It is essential to control load factor to keep high service availability by the well-balanced combination of pricing strategy and capacity increase. Controlling load factor will result in the stable growth of ridership in the long run.

High frequency, and therefore high capacity, is one of the competitive advantages of the HSR system compared with other transportation modes, as discussed in Chapter 5. Sufficient capacity supply will be needed to sustain the reliable inter-city transportation and to realize the stable ridership growth. Load factor of the HSR is the important indicator of the balance of supply (available seats) and demand (actual ridership). Our SD model suggests that if the load factor is too high, it could slow down the ridership growth due to the low availability of the seats. Therefore, it is vital for the operation company to keep the appropriate load factor by adjusting the frequency flexibly to the actual ridership growth. Considering the operation company needs time and cost to increase the frequency, it is essential for them to slightly increase price to suppress ridership growth to control demand side, while preparing long term planning of reinvestment in equipment that is required to increase the train frequency.

Recommendation 2

To secure the accessibility to the HSR stations, the operator should take into account the usage of mass transit systems as well as the technology development in transportation industries. The private operator should take action to cooperate with the public sector to increase utilization of the public transportation.

The conventional park & ride system, providing huge parking lots near the train stations, is not a wise way to keep useful accessibility to the stations. The HSR operator should start the negotiation with the public sector to provide a mass transit system to reduce the serious congestion around the stations in the near future. At the same time, considering future development of another type of last mile methods is essential to adjust the future transportation networks. For example, autonomous vehicles would be the strong candidate to access the stations in the coming decades; so providing plenty of tentative parking spaces is probably a good implementation of this aspect. This accessibility management strategy is essential from the time when the construction begins, to make the project stable in the long run.

Recommendation 3

The reservation system that enables passengers to reserve or change their departure time just before the boarding time should be implemented to keep the satisfaction of the business users who have a high value of time. To keep high retention rate is a key factor to success.

Total travel time management, including average wait time at the train station, is the key factor to compete with other modes and to keep the high satisfaction of the users. If frequent train operations allow customers to jump on the train that has just arrived, those customers do not need to wait for a long time at the station before the departure time. Especially for the business users, it is favorable to reserve or change the train tickets just before the departure time of the HSR. The online reservation system will play a significant role to allow them to do so. For example, in Tokaido and Sanyo Shinkansen in Japan, there is an online reservation system called the “Express reservation.” [77] This type of reservation system enhances the loyalty of the customers and keeps high retention rate.

9.4 Future Work

This research used a holistic approach to analyze the CLIOS system from political, economic, sociotechnical and strategic viewpoints. This research also shows the capability of using the System Dynamics method as an estimation method in the CLIOS Process. On the other hand, due to the lack of actual data in Texas, the SD model we created is based on several strong assumptions, so it could be further improved in the future. There are several points of future work, which can refine the findings of this research.

・**Introducing cost estimation model into the SD model**

In this research, the profitability of the private operator is discussed only from the revenue and ridership growth. In the SD model, the price of the ticket was determined only by the balance of supply and demand (which is load factor). There was no cost consideration, such as capital cost and its interest payment, operation cost, and maintenance cost. Thus, introducing cost function to estimate the required cost of reinvestment in the infrastructure or service improvement can be an essential refinement of this research in future.

・**Estimation of unknown parameters in Texas based on the actual data of the Texas HSR**

In this research, the SD model includes several exogenous variables such as required Time to Adopt HSR, Adoption Fraction of word of mouth and the Effectiveness of Advertising. These unknown parameters are estimated based on the primary simulation trained by using the historical data of the Taiwan HSR. This estimation relies on the strong assumption that the HSR system behavior should be somehow similar in Taiwan and Texas. However, Texan’s tendency toward transportation mode choice is likely to be different from that of Taiwanese. Comparing with the Taiwan HSR might not be the perfect case, and there might be other HSR lines that have more similarities with Texas. Therefore, while we believe that the basic structure of the SD model could be applicable to the Texas, the estimated variables in the SD model should be refined by using other HSR’s data, or much better, actual data of the Texas HSR available after its commencement of service in 2022.

9.5 Conclusions

The Texas HSR is an unprecedented HSR project in the world, in terms of its financial scheme, using foreign technology, and its operation in the highly car-centric society. There are many uncertainties such as land acquisition issue and unforeseen fund raising. Before this research, the system goal was unclear, and we did not know what is the ideal condition of the HSR project.

The representation stage of the CLIOS Process enables us to visualize, structure and understand the complex interaction between physical components and stakeholders. Each of these aspects interacts with each other and has a complex effect upon the project performance, so the holistic approach to treat this huge system as a whole was needed to derive the useful information. We came up with the idea that, in exchange for those disadvantages, the private entity has a freedom of managerial decision-making to pursue the profitability. This analysis made it clear that the profitability is the most important factor to success of the project. With the three analytical methods ("ornaments") combined with the CLIOS Process, we identified the competitive strategies that the private company should take into account to realize the competitive HSR system in the next decades. We provided some recommendations to implement these competitive strategies into reality.

As concluding remarks, the "public good" of the Texas HSR project is to serve the society by providing reliable inter-city transportation service for good, and to do so, it is necessary to make sufficient profit by sustaining the robust ridership growth. We hope the new findings of this research will help to make the Texas HSR the first successful case in the US.

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