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The Role of High-Speed Rail in Regional Development

by

Hitoshi Ono

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Signature of Author..
Department of Civil and Environmental Engineering
January 23, 1998

Certified by ....
Joseph M. Sussman
JR East Professor
Professor of Civil and Environmental Engineering
Thesis Supervisor

Accepted by ....
Joseph M. Sussman
Chairman, Departmental Committee on Graduate Studies

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ABSTRACT

The potential impact of high-speed rail on a regional economy is discussed. Firstly, the thesis discusses the current technologies of high-speed rail in Japan, Europe and the U.S. The literature of the relationship between high-speed rail and regional economy is reviewed. This literature review includes the general relationship between general transportation infrastructure and economic growth, how high-speed rail benefits regions, and several case studies of specific high-speed rail projects. Models are proposed to clarify the relationship between benefits of high-speed rail and technologies or operational strategy. Especially impacts on travel time is extensively discussed. Two models to estimate the travel time savings are proposed. Finally, the Tohoku region in Japan is discussed as a case study of different high-speed rail technologies implemented in a region.

Thesis Supervisor:	Joseph. M. Sussman
Title:	JR East Professor Professor of Civil and Environmental Engineering

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1. Introduction

1.1 Introduction

Currently, much attention is being given to high-speed rail (HSR) system around the world. Much of it is due to the several environmental issues arising recently. Global warming, as well as air pollution, has become a major concern in the world, and people have begun to understand that environmental issues may become significant hindrances for further economic growth. Consequently, "sustainability" has become a keyword in any large-scale projects including transportation infrastructure investments. Generally high-speed rail technology has been regarded as less harmful environmentally in terms of air pollution and energy consumption, and more regions are examining high-speed rail once again.

It is also noted that congestion on highways, at airports and in air corridors has become serious as traffic grows, and the loss on economy due to the serious congestion has become a significant issue. A HSR system may reduce the level of congestion on highways, at airports and in air corridors by diverting passengers to rail transportation.

The first HSR in the world was the Japanese Tokaido Shinkansen (*new-trunk-line*) connecting two metropolitan areas of Tokyo and Osaka, which began its operation in 1964. The French TGV (*Train à Grande Vitesse*), another important system in the world, began its first operation between Paris and Lyon in 1981. Since then, both systems have enjoyed high speed, high reliability, high operational frequency, and high level of service.

The success of the Shinkansen and the TGV convinced people of the important roles that a HSR could play in regional development. It has become accepted wisdom that transportation infrastructure is not only necessary for regional economic development, but can actually promote relatively faster rates of growth.(Vickerman[1], 1996) In this context, since its birth a high-speed rail system has been always regarded as one of the public infrastructure investments that could develop a regional economy and society. For example, most Japanese people agreed that the

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[1] Vickerman, Roger(1996), "The economic impact of high speed rail", *Mass Transit*, Sept./Oct., pp.63-70

construction of Tokaido Shinkansen line was a great success from both operational and societal perspectives. It is noted that an issue of regional equity also becomes important in a nation where success of HSR has come into reality in some of its regions. When a HSR looks effective as a boost to regional economic development, people in regions with no HSR tend to regard it as a panacea for their own economy. Then, the construction of HSR becomes a highly political issue for policy makers who are supported by regional residents.

Consequently, the network of HSR has been expanded slowly but steadily around the world. If we define a high-speed rail (HSR) as a railway system operating daily at speeds of 150 mph (240 km/h) or greater, the systems in the world are as follows; the French TGV, the Japanese Shinkansen, the German InterCity Express (ICE), the Italian ETR-450, and the Swedish X-2000. (Sands[2], 1993) The Spanish AVE can be now included in this category.

Table 1-1: High Speed Rail Technologies around World[3]

	TGV	Shinkansen	ICE	ETR-500	AVE
Country	France	Japan	Germany	Italy	Spain
Operational Maximum Speed	187 mph	187 mph	175 mph	187 mph	156 mph
Number of Routes	3	5	2	1	1
Dedicated Rights-of-way	800 miles	1,220 miles	265 miles	346 miles	294 miles

Furthermore, some second-stage implementations of HSR in several regions are observed. For example, the development of an integrated high-speed rail network has been one of the central features of recent European Union (EC) transport infrastructure policy. (Vickerman[4], 1997) It means the several HSR implementations already in place in France, Germany and other European countries are now considered as parts of an integrated high-speed rail network in the proposed integrated European economy.

Also in Japan, where the Shinkansen network has been widely regarded as a major success, three new HSR lines have started their operation in the 1990s and three more routes are now under construction. At the same time, further speed-up of existing lines has occurred. In March 1997,

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[2] Sands, Brian D.(1993), "The Development Effects of High-Speed Rail Stations and Implications for California", Working paper of University of California, Berkeley, Institute of Urban and Regional Development);No.566

[3] Source: Strohl, Mitchell, P.(1993), "Europe's High Speed Trains: A study in Geo-Economics" and *Kotsu Shinbun*(Transportation Newspaper) (1997) (in Japanese)

the Sanyo Shinkansen line, which connects Shin-Osaka, Osaka and Hakata, Kyushu, increased the operational maximum speed from 275 km/h to 300 km/h[5].

Even in the United States, where air and automobile transportation has been dominant in the inter-city passenger travel market, a new "incremental" high-speed rail is being developed by Amtrak. It will begin its operation between New York City and Boston through the North East Corridor (NEC) in 1999. In the future, we may see the new technology of *Maglev*, or magnetic levitated trains, being developed and tested in Japan and Germany.

However, it is not an easy nor straightforward process to realize an implementation of HSR. First, financial feasibility is always a key issue not only for a country like the U.S. where currently no HSR exists but also for a country like Japan where new routes will go through less populated thus less profitable corridors. Second, the idea itself that a HSR has positive impacts on regional economy has been doubted. For example, there is an argument that a HSR system was more beneficial to relatively large cities than to smaller cities so that it might accelerate concentration into metropolitan area rather than spreading development. (Ueda, Nakamura[6], 1989) The debates on HSR impacts on regions have not ended yet.

As seen in the failure of Texas TGV project in the early 1990s or the failure of Japanese Narita Shinkansen project in 1970s, the success of HSR implementation is not always guaranteed and there are many issues that have to be solved before the realization of HSR. Furthermore, even after a HSR system starts its operation, the magnitude of success has varied. While several systems are regarded as a fair success, several systems exists that received less positive appraisals in terms of its profitability and impacts on regions.

It also has to be noted that attitudes toward HSR are quite different among nations and regions. In Europe and East Asia, HSR has been regarded as a socially desirable mode of inter-city transportation, while in the U.S. its usefulness often tends to be doubted and challenged. Even environmental issues such as noise and pollution problems may work quite differently for a HSR system depending on a person's viewpoint. In some countries a HSR system can be seen as

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[4] Vickerman, Roger (1997), " High-speed Rail in Europe: experience and issues for future development", Annals of Regional Science:31:pp.21-38

[5] Source: *Kotsu Shinbun* (Transportation Newspaper) (1997): December 8,pp.2 (in Japanese)

environmentally desirable due to less energy consumption, while its noise can be a significant concern in other countries.

1.2 Motivation of Thesis

As argued briefly in the previous section, a high-speed rail system has been recognized as one of the infrastructure investments for regional economic development. However, the effectiveness of HSR as a tool for regional development has not been proved yet, and its high construction cost is always a major barrier to its implementation.

In addition, a HSR has different characteristics than general transportation infrastructure like roads or commuter railroads. First it basically serves only passengers and not freight. Second, to attain high operational speeds, there are limits on the number of stations on the route. Therefore, the areas affected may be limited to areas near the stations. Third, passengers with business purpose will be dominant because time is likely to be the major economic determinant for the business traveler.(Strohl[7], 1993) As a result, direct recipients of HSR benefits are relatively limited compared to highways and other infrastructure; this makes it relatively harder to receive unanimous support in some countries like the U.S.

However, it is noted that in the 1990s several HSR options with different levels of technology and with different levels of cost have been developed. This is in contrast to the 1980s when only the French TGV or the Japanese Shinkansen technologies could be a candidate of HSR. It means that a region does not necessarily have to construct a costly HSR like TGV or Shinkansen but now has options to utilize existing railroad infrastructure and network as much as possible to reduce the initial construction cost. The concepts of "incremental" HSR in the U.S. and "Mini-Shinkansen" in Japan are the examples and will be discussed later in more detail. A brief explanation of these two concepts is given here.

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[6] Ueda, Takayuki, Nakamura, Hideo(1989), "The Impact of Shinkansen on Regional Development", *Doboku-keikakugaku kenkyu-koenshu*:12 (in Japanese)

[7] Strohl, Mitchell, P.(1993), "Europe's High Speed Trains: A study in Geo-Economics", pp.25

The concept of "incremental HSR" is basically the utilization by high-speed trains of existing rights-of-way sharing them with freight trains and commuter trains. This concept has been developed in the U.S. and its first implementation will be the Northeast corridor between New York City and Boston. The tracks are improved and part of the route between New Haven, CT and Boston, MA is electrified. Several issues, safety and line congestion have arisen by sharing its right-of-way with other types of trains, but its most attractive point is the cheaper construction cost, compared with a dedicated right-of-way.

The concept of the "Mini Shinkansen" in Japan includes; (1) improving existing conventional right-of-way and widening gauge to the international standard, (2) using train sets that can run both on conventional and dedicated Shinkansen infrastructure at 168 mph (275 km/h) and on newly improved rights-of-way at 81 mph (130 km/h).

Figure 1-1: Concept of Mini Shinkansen

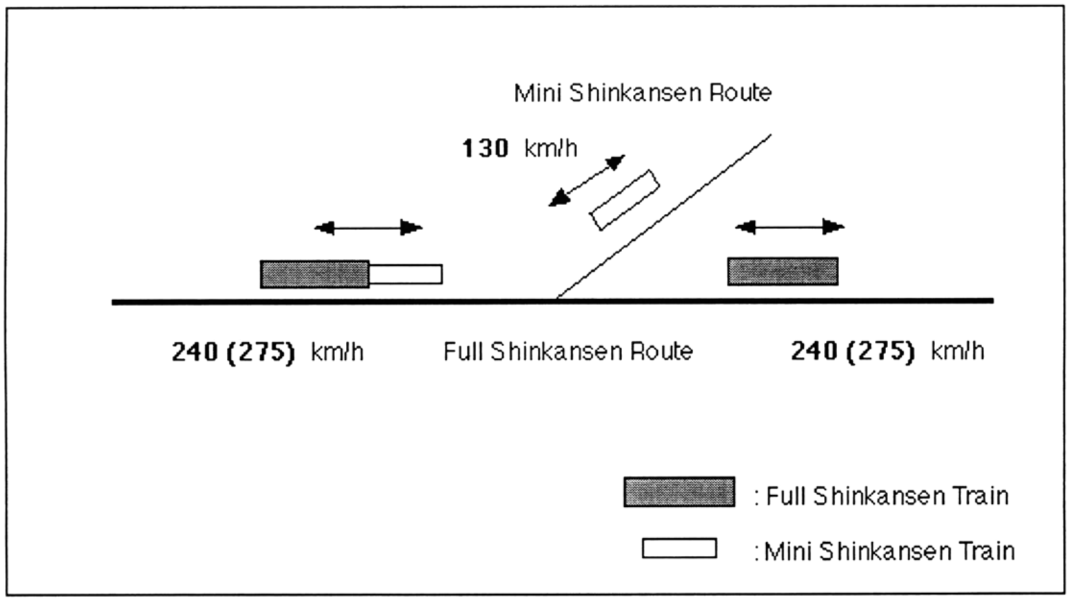

Figure 1-2: Mini Shinkansen[8]

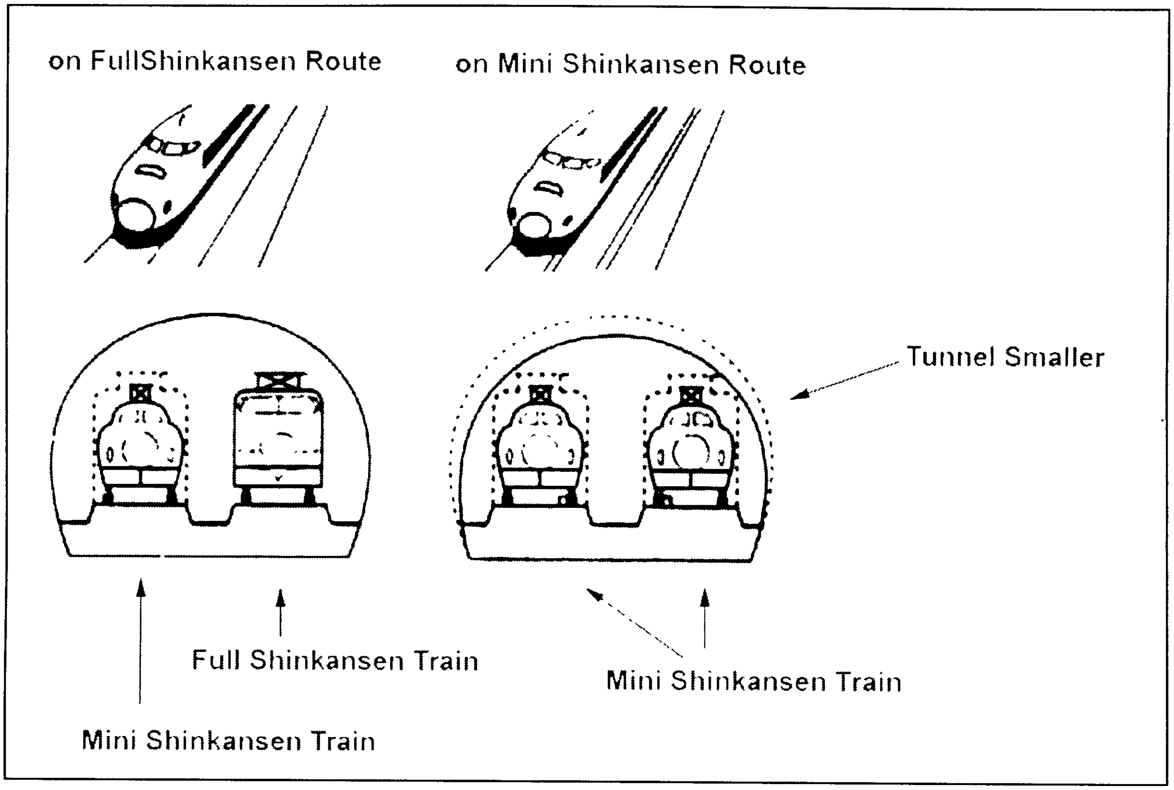

Table 1-2: Comparison of Full and Mini Shinkansen

	Full Shinkansen	Mini Shinkansen
Gauge	1.435 meter (standard gauge)	1.435 meter (standard gauge)
Maximum Speed	300 km/h	130 km/h (275 km/h)
Width of Car Bodies	3.38 meter	2.9 meter
Minimum Radius of Curves in Main Track	2,500 meter (Tokaido line) 4,000 meter (Other lines)	800 meter
Grade Crossings	Do not exist	Exist

A major advantage of Mini-Shinkansen is the construction cost saving by utilizing existing right-of-way. In Japan, two new Shinkansen began operation in 1997; Nagano Full Shinkansen and Akita Mini Shinkansen. When compared, the construction cost of Akita Mini Shinkansen per kilometer was only 7 % of that of Nagano Full Shinkansen. (See Table 2-5) Although Mini Shinkansen is slower than conventional "Full" Shinkansen, it costs much less because it needs

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[8] Source: *Japan Railway & Transport Review*(1994) No.1, pp.9

construction basically only to widen the gauge of right-of-way. No additional land acquisition nor widening bridges or tunnels are necessary because the exterior body size of new train is identical to the existing narrow-gauge trains.

In spite of the limited reduction of in-vehicle travel time, Mini Shinkansen has been welcomed by its users and region because it has eliminated the physical transfer at connecting terminal and improved psychological accessibility of the region. For example, in terms of Yamagata Mini Shinkansen line, once passengers from Tokyo to Yamagata had to take a Tohoku Shinkansen train from Tokyo to Fukushima, and had to transfer to another narrow-gauge express to get to Yamagata before the completion of Mini Shinkansen. Now they can go from Tokyo to Yamagata directly without any transfer after boarding a train at Tokyo station. When converted into in-vehicle travel time, the value of elimination of transfer varies among people, but JR-East[9] says it equals to about 30 minutes in-vehicle time reduction, while other sources say it might be equal to 45 minutes reduction in some cases[10].

As seen, the utilization of existing facility is the most important advantage for both Incremental HSR and Mini Shinkansen systems. These relatively new concepts of incremental HSR and Mini Shinkansen can be attractive options of lower construction cost, especially if the most important reason to oppose a HSR project is economic feasibility.

It is also noted that the increase of speed and reduction in travel time has been considered as a major benefit expected from a HSR project, because it and fare level directly affect potential ridership. However, due to the slower speed, not all the merits of conventional HSR are realized by Incremental HSR or Mini Shinkansen. Under these circumstances, it has become more important to analyze advantages and disadvantages of HSR technologies from the viewpoint of benefits and costs at different speed levels.

This thesis will focus on the change of travel time resulting from various kinds of HSR. In particular, this research will analyze how the various HSR technologies lead to differences in HSR operation and travel time, and how a case study region might be affected by several levels of HSR deployment.

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[9] Source: JR-East (1997) (not published)

1.3 Thesis Organization

This thesis begins with Chapter 2, discussing various technologies of high-speed rail around the world. Mainly HSR systems in Japan, Europe (especially France and Germany) and United States are discussed. Then, in Chapter 3, the literature of high-speed rail and regional economic development is reviewed. It includes general relationship between public infrastructure investment and economic development, such as Aschauer's work in 1989 or Nadiri's work in 1996. It also includes several studies of specific transportation corridors, and several studies for specific methods to capture the benefits of high-speed rail. Some of qualitative studies providing analytical frameworks are reviewed as well as quantitative studies, since it is important to understand the merits and demerits of HSR both quantitatively and qualitatively. Chapter 4 introduces an analytical method to estimate the impact of high-speed rail on regions. Among the several benefits incurred by a HSR, travel time reduction impacts are extensively discussed. Methods to calculate the travel time saving are introduced and applied to a hypothetical region. In Chapter 5, the Tohoku region in northern Japan is studied as a case study of relationship between high-speed rail and regional development. Finally Chapter 6 gives conclusions and recommendations for future high-speed rail implementations.

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[10] Source: Nagayama, Kinya(1997), "Tohoku no Kuni zukuri ni Ikiru", Testsudo Journal(Railway Journal), June, pp.30-36 (in Japanese)

2. Technologies for High-Speed Rail Systems

In this chapter, the current high-speed rail technologies of Japan, Europe, and U.S. are reviewed. As for Japan, several recent implementations of HSR with different technologies are discussed with the historical and operational perspective. Several European technologies including French TGV and German ICE are discussed as well as the concept of the European high-speed network. Finally, the current project of incremental high-speed rail in Northeast corridor of the U.S. is discussed. In this chapter, we focus on the geographical and operational characteristics of each HSR; HSR impacts (e.g. economic growth, land use pattern) on regions are discussed in Chapter 3.

2.1 Japan

About 125 million Japanese people live on a small group of islands. The population density of this country is 335 per square kilometer. Given the mountains, the land remaining under cultivation, the ubiquitous manufacturing plants, and a lot of city streets, the living space is even more constricted. (Strohl[11], 1993) First, the brief history and characteristics of Japan's inter-city rail system are reviewed and the concepts of "Full" Shinkansen and "Mini" Shinkansen are introduced. All Shinkansen lines in operation are discussed, and finally the current implementation of Maglev (magnetic levitated trains) technology in Japan is introduced.

2.1.1 *Pre High-Speed Age: Narrow-gauge Rail Network*

One of the characteristics in Japan's traditional railroad network is the narrow gauge of tracks. This narrow gauge is 3 feet 6 inch (1,067mm) width, and narrower than 4 feet 8.5 inch (1,435mm) of international (or "standard" gauge). The Japanese government in the nineteenth century adopted the narrower gauge because of less construction and repair cost. From the technological point of view, however, this narrow gauge has become a major constraint to realizing higher speed train operation. Due to lack of stability at high speed, it is unlikely that any train can run at the speed of more than 200km/h on narrow-gauge tracks.

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[11] Ibid. 7, pp.55

In addition, mainly due to many grade crossings on the network, the Japan's Ministry of Transport (MOT) has required that every train must be able to stop within 0.6 km from its operational maximum speed to avoid or reduce the damage of collision. This regulation of braking capability has been also a major obstacle to increase the maximum speed of trains running on the narrow-gauge tracks, because the cost to eliminate existing grade crossings is not negligible. The maximum speed of trains on the narrow gauge tracks is generally 130km/h at the current level of technology, although 160 km/h operation is experimentally allowed on the new dedicated right-of-way of narrow-gauge with no grade crossings. Improving braking ability will permit higher maximum speed and 150km/h operation is said to be possible in the future, but it is not still a dramatic speed-up. It is also noted that this regulation refers to the emergency brake system only, and its change may not necessarily increase normal operational deceleration rate because comfort of passengers will deteriorate at the higher deceleration rate.

These technical disadvantages of the current narrow-gauge network had led the Japan National Railroad (JNR) to develop a completely new, dedicated high-speed passenger rail, which was named Shinkansen, which means "new-trunk-line" in Japanese.

2.1.2 *"Full" Shinkansen - the conventional Shinkansen system*

The "Full" Shinkansen refers to the conventional full-size Shinkansen system, distinguished from "Mini" Shinkansen, which is explained in the following section. When "Mini" Shinkansen appeared, original Shinkansen system had to be distinguished from it. The name of "Full" refers to full size of Shinkansen, and a "Full" Shinkansen line has totally dedicated right-of-way for high-speed passenger rail service, with all trains having a maximum speed of 240 km/h or higher. It adopted the international standard of 4 feet 8.5 inch (1,435mm) gauge rather than the traditional narrow gauge so that no compatibility with the traditional rail network was realized. It is dedicated to passenger transportation and no freight trains are allowed to run on the routes. "Full" Shinkansen has no grade crossings on its dedicated right-of-way and much protection has been made with implementation of an advanced signal and safety system. Therefore, Full Shinkansen has no requirement in terms of braking capability that traditional narrow-gauge trains have. It takes more than 2 km to stop from its maximum speed.

The Japanese Shinkansen is the world's longest-running high-speed rail system. (Sands[12],1993) Tokaido Shinkansen line, the first Shinkansen, began its operation in 1964 between Tokyo and Osaka to cope with the high travel demand that had caused saturation on the conventional railroad. Soon after, Sanyo Shinkansen line was constructed as an extension of Tokaido Shinkansen. Since then, the network of Shinkansen lines has expanded through the nation. It is said that the Shinkansen network has been almost completed on all densely populated corridors in Japan and the focus is now on further speed-up on existing Shinkansen routes and expansion of the Shinkansen network to less dense and less economically thriving regions.

In terms of operation, a Shinkansen system generally has several types of train depending on the stopping pattern at stations. For example, Tokaido Shinkansen consists of 3 train types; "Nozomi (hope)" the super-express, "Hikari (light)" the express, and "Kodama (echo)". Nozomi and Hikari type trains stop only at limited stations, while Kodama type stops all stations en route.

Note that adding stops en route gives significant impact on travel time both by acceleration from halt to the maximum speed and deceleration from the maximum speed to complete stop. Compared to conventional trains, the maximum speed of HSR is higher and the rate of acceleration and deceleration is generally lower due to the setting of gear rate to maximize top speed. The maximum speed and acceleration rate are traded-off at a certain level of technology. Consequently, adding stops to HSR operation will have greater impact on travel time. Roughly speaking, one additional stop on Full Shinkansen route adds an additional 5 minutes to the whole travel time. Thus it is reasonable that a Nozomi, which can run at the speed of 275 km/h on Tokaido Shinkansen line, has very limited stops en route; at Shin-Yokohama, Nagoya, Kyoto at most. The fare of Nozomi trains is set higher than other two types due to the shorter travel time.

It is also noted that newer trains can run faster due to the advanced technologies, but from a financial perspective it is not possible to replace all train sets at the same time. As a result, several sets of trains with different maximum speed and different age are used simultaneously on the route. Generally speaking, newer train sets are used for express-type trains with less stops. In terms of Tokaido Shinkansen, the newest train sets are used for Nozomi super-express trains while Kodama uses the oldest train sets.

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[12] Ibid. 2

Table 2-1: Characteristics of Shinkansen Lines (as of 1997) [13]

	Type	Year of completion	Route Length	Operational Maximum Speed	Travel time of the fastest train	Average Speed
Tokaido	Full	1964	515 km	275 km/h	2 hr. 30 min.	221.2 km/h
Sanyo	Full	1975	562 km	300 km/h	2 hr. 17 min.	242.6 km/h
Tohoku	Full	1991	501 km	275 km/h	2 hr. 21 min.	227.7 km/h
Joetsu	Full	1982•	275 km	275 km/h	1 hr. 19 min.	205.1 km/h
Nagano	Full	1997	126 km	260 km/h	42 minutes	167.1 km/h
Yamagata	Mini	1992	87 km	130 km/h	1 hr. 01 min.	85.6 km/h
Akita	Mini	1997	127 km	130 km/h	1 hr. 24 min.	90.7 km/h

Figure 2-1: The Shinkansen Network in Japan (1997)[14]

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[13] Source: JR Timetable(1997), December (in Japanese)
from Aomori Prefecture: http://www.pref.aomori.jp/newline/sin-06.html (in Japanese)

• When construction between Omiya and Niigata was completed.

[14] Source: Railway Technical Research Institute (RTRI) (1997)

2.1.2.1 The Legitimacy of 'Full" Shinkansen - Seibi Shinkansen Act

After the success of Tokaido and Sanyo Shinkansen lines, the whole nation revised their suspicious view toward HSR and began to think of it as indispensable to the regional development. In other words, regions without a Shinkansen line began to worry that they would suffer comparative disadvantage in future development. It is noted that Japan's rural areas normally have had stronger political power than metropolitan areas, and mainly upon their request, the Seibi Shinkansen Act was proclaimed in 1970. The purpose of this law is explained as follows:

> *We recognize the importance of a high speed transportation network to promote national integrated development. Therefore, we will construct the national Shinkansen network to expand the national economy and make all parts of the country accessible to people*[15].

This Seibi Shinkansen Act refers only to "Full" Shinkansen because the concept of "Mini" Shinkansen was not born yet. According to this law, basic five lines were planned. (See Figure 2-2) Among these five lines, the construction of Tohoku and Joetsu Shinkansen lines began in the northern areas of Japan in 1971. However, the profitability of these two Shinkansen is less than Tokaido and Sanyo Shinkansen. (See Table 2-2) In addition, the budget of the Japan National Railroads (JNR), which owned and operated national rail network including Shinkansen, became catastrophic because of its excessive investment and ineffective management in 1970s and 80s and its huge deficit finally halted any further construction of Seibi Shinkansen after the completion of Tohoku and Joetsu Shinkansen.

After the privatization of JNR in 1987, construction resumed in 1989 and the Nagano Shinkansen was constructed and started its revenue operation in October 1997 with the financial risk of the project covered by the Japanese government. Three other Seibi Shinkansen routes are currently under construction; Tohoku route extension (Morioka to Hachinohe), Hokuriku route (Itoigawa to Uozu and Isurugi to Kanazawa), and Kyushu route (Yatsushiro to Kagoshima). There are also lines that have been approved by Diet but with construction not started yet, and lines in the "basic plan" which are not approved by Diet.

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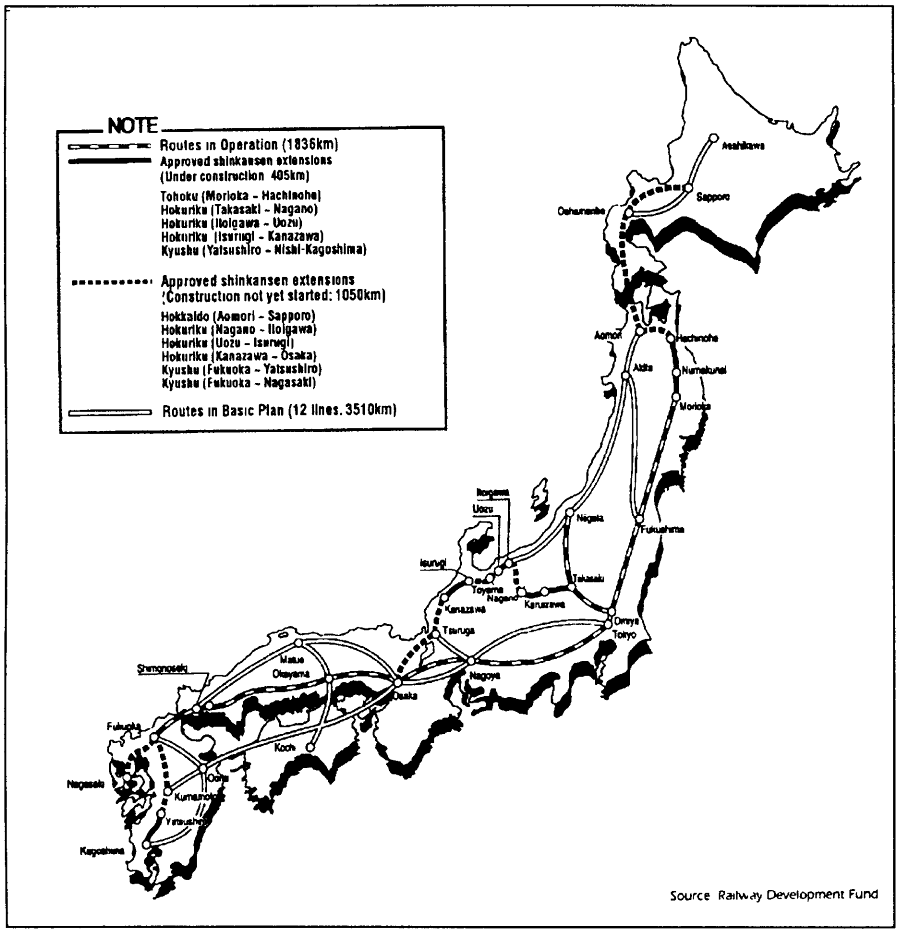
[15] Quoted from: Mitani, Kuniaki(1994), "A Comparative Analysis of Railway Project Financing: Case Studies of High-Speed Railway Projects in the U.S. and Japan"

Figure 2-2: Seibi Shinkansen Plan[16]



Source Railway Development Fund

Table 2-2: Shinkansen Revenue and Expense (FY1985) (Billion Yen)

	Tokaido	Sanyo	Tohoku	Joetsu	Total
Revenue	6756	2843	2076	815	12490
Expense	2857	2065	3667	1594	10183
Profit/Loss	3899	778	-1591	-779	2307

Source: JNR Audit Report -FY1986[17]

Table 2-3: The Status of Seibi Shinkansen in 1997

	Construction Status	Length
Routes in Operation already[♦]	Finished	1,836 km
Extensions Approved by Diet	Under Construction	405 km
Extensions Approved by Diet	Not Started	1,050 km
Routes in Basic Plan	Not Approved	3,510 km

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[16] Source: Railway Development Fund, quoted from: Ono Akio(1997), "Role and Functions of Railway Development Fund", *Japan Railway & Transport Review*, No.11, April, pp.15

[17] Quoted from: Kakumoto, Ryohei(1997), "Transportation Investment and Japan's Experience", *Japan Railway & Transport Review*, April, pp.10

[♦] Includes Tokaido, Sanyo, Tohoku, Joetsu, Nagano Shinkansens

2.1.3 *Mini Shinkansen*

This relatively new concept of HSR began in 1980s, when the huge deficit of the Japan National Railroads (JNR) was a significant political issue. This concept is to upgrade existing tracks of narrow gauge at less cost than new right-of way and provide "through and direct" high-speed rail service between these upgraded tracks and conventional "Full" Shinkansen routes. The newly built trainsets run through both on Mini Shinkansen route and Full Shinkansen route and have freed passengers from changing trains at the connecting terminal. The main objective of Mini Shinkansen is to minimize the construction cost and operational costs for the regions with less population density and less travel demand. (See Figure 1-1)

The Yamagata "Mini Shinkansen" line between Fukushima and Yamagata started its revenue operation in 1992 and Akita Mini Shinkansen line between Morioka and Akita started in 1997. At present the extension of Yamagata Mini Shinkansen from Yamagata to Shinjo is under construction.

The Mini Shinkansen scheme requires improvement on both infrastructure and rolling stocks. As for infrastructure, the gauge of right-of way is widened to international standard (4'8.5") from traditional narrow gauge (3'6"). Thus, existing local or freight trains can no longer operate on the upgraded route. However, an expensive 3-rail track has been introduced partially to allow narrow-gauge trains, mainly to maintain the nationwide freight rail network.

It is noted that infrastructure other than tracks basically requires no modification, because the exterior size of Mini Shinkansen train is identical to existing local trains. It is not necessary to widen the cross section of tunnel nor the width of bridge. As a result, Mini Shinkansen scheme makes much savings in infrastructure cost compared with Full Shinkansen construction.

On the Mini Shinkansen routes, however, basically curves en route remain as same as previous narrow-gauge right-of-way. The existing railroads generally have many curves due to the mountainous terrain of Japan, but straightening curve will cost in the same order of the Full Shinkansen due to the high land acquisition costs and severe terrain situation for construction.

Therefore, partial speed restriction on tight curves is still applied to the Mini Shinkansen trains, hindering speed-up effect.

In addition, the maximum speed cannot be increased significantly due to the regulation by the Ministry of Transport, which requires all Mini Shinkansen trains to stop within 0.6 km from the maximum speed. There remain several grade crossings on the Mini Shinkansen route and in terms of signal and safety systems, it is basically identical to the conventional narrow-gauge trains, which is comparatively at the lower safety standard than the Full Shinkansen system. Consequently, the same regulation of narrow-gauge trains is applied to the Mini Shinkansen and the present maximum speed on the line is set to 130 km/h. So the travel time reduction on Mini Shinkansen routes itself is not drastic.

In terms of rolling stock, totally new sets of trains are introduced both for Mini-Shinkansen and local passenger trains for the widened tracks. Mini Shinkansen trains also can run on the dedicated rights-of-way of the Full Shinkansen routes at the same speed as Full Shinkansen train. They are basically coupled with a Full Shinkansen train on the Full Shinkansen dedicated rights-of-way and coupling and uncoupling are made automatically at the branch-off station. (See Figure 1-1) For example, a Yamagata Mini Shinkansen train runs coupled with a Tohoku Full Shinkansen train between Tokyo and Fukushima, and is coupled or uncoupled at Fukushima Station, and runs separately between Fukushima and Yamagata. Those coupling and uncoupling are completely automated, and take only 1 to 2 minutes. The passengers don't have to change trains physically at the previous branch-off station between Full Shinkansen and conventional trains; They now just wait on board while the train is coupled or uncoupled.

Although the width of wheels of Mini Shinkansen is set to Full Shinkansen size, the exterior size of trains remains same as existing conventional trains running on the narrow-gauge routes. Since it is smaller than Full Shinkansen trains, there becomes a gap between a Mini Shinkansen body and the platform of stations on Full Shinkansen route, and a step automatically comes up at each door from the body of Mini Shinkansen to avoid passengers falling into the gap.

It is noted that the frequency of operation is an important issue to be competitive with other transportation mode(especially air). The Mini Shinkansen service is currently more frequent than competitive air routes. (This issue will be discussed in Chapter 6.) However, the travel demand on the Mini Shinkansen routes is relatively lower, so the number of cars of a train should be less than those of Full Shinkansen trains, which normally have more ridership. For example, a Yamagata Mini Shinkansen train has 7 cars and Akita Mini Shinkansen train has 5 cars, while a typical Tokaido Shinkansen train has 16 cars. It is also noted that the short length of train allows coupling with other trains and saves the cost of crew on the Full Shinkansen route.

The advantages of Mini Shinkansen are summarized as follows:

- Less construction cost which allows HSR implementation on routes with less travel demand. For example, both of the Hokuriku (Nagano) Full Shinkansen and the Akita Mini Shinkansen were constructed until 1997 and the unit construction cost of Akita Mini Shinkansen for infrastructure is only 7 percent of that of the Nagano Full Shinkansen. (See Table 2-4 and Table 2-5)
- A supplementary way to utilize existing Full Shinkansen network. Note that it works well only if the travel demand from the Full Shinkansen route is relatively high.
- Elimination of changing trains which is the large advantage both for travel time and passengers' comfort. Note that the nearer to the branch-off terminal a Mini Shinkansen station locates, the larger benefits it gains, since the transfer time is a larger proportion in the total travel time.

On the other hand, the disadvantages of Mini Shinkansen are as follows:

- Limited speed-up effect. The speed up effect is limited unless curves are straightened and grade crossings are removed to ease the governmental safety regulation. Since the reduction of construction cost is the first priority to ensure the feasibility of the project, this option is not being used.
- Cutting nationwide freight rail network into pieces. Existing network of freight railroads has utilized the traditional narrower gauge and virtually all freight locomotives are able to run only on the narrow-gauge tracks. So the widening tracks for Mini Shinkansen means basically no freight rail transportation is possible on the route. The partial solution has been made to implement tracks with 3 rails for necessary sections, but it is more complicated and expensive, which might negate the cost reduction impact of Mini Shinkansen scheme.
- Regardless of the efforts to reduce the cost, the financial profitability of a Mini Shinkansen project has been still ambiguous due to the small travel demand. The national and prefecture governments have subsidized Mini Shinkansen projects to reduce risk of the project.

Table 2-4: The Japanese Full Shinkansen Construction Costs[18•]

Line and Year of Completion	Construction Cost (billion yen)	Construction Route Length (km)	Construction Cost per kilometer (million yen)
Tokaido (1964)	430	515	830
Sanyo (1975)	910	562	1,620
Tohoku (1991)	2,400	501	4,790
Joetsu (1982)	1,530	275	5,560
Hokuriku (1997)	790	126	6,270

Table 2-5: The Japanese Mini Shinkansen Construction Costs[19]

Line and Year of Completion	Construction Cost (billion yen)	Construction Route Length (km)	Construction Cost per kilometer (million yen)	Comparison between lines (Hokuriku = 1)
Yamagata (1992)	38.0	87.1	436	0.07
Akita (1997)	59.8	127.3	470	0.07

In the following sections, all Shinkansen lines are explained in the chronological order.

2.1.4 *Tokaido Shinkansen*

Tokaido Shinkansen is the first Shinkansen and first HSR implemented in the world. Extending in a generally southwest direction from Tokyo (population 13 million) to Osaka (population 2.54 million) 515 km away is the Tokaido megalopolis, a corridor in which are located Kawasaki (1.41 million), Yokohama (3.1 million), Nagoya (2.1 million) and Kyoto (1.4 million). In all about 50 million people, or 40% of the Japanese population, live along the Tokaido path. (Strohl[20], 1993) The Tokaido Shinkansen line runs through this densely populated corridor where several large cities are interconnected. The travel demand on this corridor is very high and 11 Shinkansen trains run in a hour at the daily peak. Consequently, the operational capacity of Tokaido Shinkansen line is expected to reach its maximum soon as ridership grows, and this forecast has given a legitimacy for advocates of construction of another new high-speed ground

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[18] Source: Hirota, Ryosuke(1997), "Shinkansen infrastructure cost and development of technology in construction", *Special Lecture in the 83rd Annual Meeting of Japan Society of Civil Engineers* (in Japanese)

[•] Construction costs are not adjusted by the inflation.

[19] Source: JR-East (1997), (in Japanese)

[20] Ibid. 7, pp.55

transportation system (HSGT) between Tokyo and Osaka, which would be the first and only Maglev in Japan.

The current maximum speed of Tokaido Shinkansen is 275 km/h of Nozomi super-express type, and it connects Tokyo and Osaka (515km) with 2 hour 30 minutes.[21] The passenger share of the Tokaido Shinkansen on Tokyo to Osaka is 83% while air takes only 17%.[22]

All the Japanese people might agree that Tokaido Shinkansen has been a great success and its success led to further construction of Sanyo, Tohoku, and Joetsu Shinkansen.

2.1.5 *Sanyo Shinkansen*

Soon after the completion of Tokaido Shinkansen line, Sanyo Shinkansen line was planned to extend the Tokaido Shinkansen line to the west to Hakata, through the second industrialized corridor in Japan. (See Figure 2-1) A survey in 1965 proved the operational feasibility. Construction started in 1969 and reached Hakata in 1975. This extension is 553.7 km length and connects the following major cities: Kobe (1.42 million people), Okayama (550 thousand), Hiroshima (189 thousand), Kokura (1.06 million), and Hakata (1.07 million). (Strohl[23], 1993) The combined Tokaido-Sanyo Shinkansen lines are in a traffic catchment area containing two-thirds of the Japanese population and about three fourths of the country's economy. While a success, the Sanyo line is less profitable than the Tokaido section. (Strohl[24], 1993) The Sanyo Shinkansen line has faced severe competition with air transportation, and in 1997, the passenger share on Hakata to Tokyo is only 12% while air taking 88%. Also, its share on Hakata to Nagoya is 30%, and that on Hakata to Osaka is 60%.[25] Under this severe competition with air, many speed-up efforts have been made and 300 km/h operation has been taken place since March 1997 and connects Hakata and Osaka with 2 hour 17 minutes.[26]

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[21] Source: JR Timetable(1997), Dec. (in Japanese)

[22] Source: Asahi Shinbun(1997), Nov.20 (in Japanese)

[23] Ibid. 7, pp.63

[24] Ibid. 7, pp.63

[25] Source: *Kotsu Shinbun* (Transport Newspaper) (1997), Dec.8, pp.2 (in Japanese)

[26] Ibid. 21

2.1.6 *Tohoku and Joetsu Shinkansen*

The construction of Tohoku and Joetsu Shinkansen lines was started in 1971 according to the Seibi Shinkansen Act. Tohoku Shinkansen line is 535 km length and connects Tokyo, Omiya (360 thousand people), Utsunomiya (380 thousand), Kouriyama (302 thousand), Sendai (970 thousand), and Morioka (290 thousand). Joetsu Shinkansen line is 303 km length and connects Tokyo, Omiya, Takasaki (230 thousand) and Niigata (450 thousand people). (Strohl[27], 1993) Evidently instrumental in the authorization for construction was the fact that at the time the Japanese prime minister was Kakuei Tanaka, whose hometown was Niigata. A special government funding was granted for the line's building. (Strohl[28], 1993) Both Tohoku and Joetsu Shinkansen line started its operation partially in 1982 from Omiya to Morioka and Niigata, respectively. The remaining part between Omiya and Ueno was completed in 1985, and between Ueno and Tokyo in June, 1991. (See Figure 2-1)

The Tohoku and Joetsu line run through less populated areas than the Tokaido and Sanyo Shinkansen lines and their financial profitability was not proved. (see the Table 2-2 on pp.26) In addition, the construction cost was higher because of the mountainous terrain and more severe winter conditions. For example, the Joetsu Shinkansen line has 106 tunnels so that forty percent of the line is in tunnels and tunnels generally are costly. It also travels through Japan's heaviest snowfall regions, and very elaborate measures are taken to ensure undelayed train movement. At trackside are hot air devices, automatic snow-removing sprinklers, and hot water jets. (Strohl[29], 1993)

2.1.7 *Yamagata Mini Shinkansen*

While new start of Shinkansen construction was frozen due to the huge deficit of JNR, some of local governments in northern Japan still wanted how to construct a HSR in their regions. Yamagata prefecture was one of them and originally demanded "Full" Shinkansen for their region. However, after they understood that they had very slight chance to get it for their region, they changed the strategy to introduce "Mini" Shinkansen instead of Full Shinkansen. The Yamagata Mini Shinkansen line was the first implementation of "Mini" Shinkansen concept in Japan. The construction started in 1989 and commercial service began in 1994.

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[27] Ibid. 7, pp.63
[28] Ibid. 7, pp.64
[29] Ibid. 7, pp.65

The route is 87 km from Yamagata to Fukushima, a station connecting to Tohoku Shinkansen line. All Yamagata Shinkansen trains run between Yamagata and Tokyo directly. Between Yamagata and Fukushima they run at the maximum speed of 130 km/h, and run coupled with a Tohoku Full Shinkansen train between Fukushima and Tokyo at the maximum speed of 240 km/h. Although the maximum speed on the route is 130 km/h, there remains significant speed restriction. For example, at Itaya *toge*(mountain pass), the speed limit is 60 km/h (70 km/h on the opposite direction) due to the steep curve and gradient. The length of route that a train can run at 130 km/h is only 27.4 km (31%) and 40.1 km (46%) for both directions.[30]

The travel time between Tokyo and Yamagata in 1997 is 2 hour 27 minutes and 56 minutes reduction from 3 hour 23 minutes in 1987. (JR-East[31], 1997)

2.1.8 *Akita Mini Shinkansen*

The Akita Shinkansen line, which started commercial service in March 1997, is the second implementation of Mini Shinkansen concept. As in the Yamagata prefecture, Akita prefecture without the Seibi Shinkansen plan in its region decided to finance the Mini Shinkansen project of 127 km length between Akita city and Morioka station, the current terminal of Tohoku Shinkansen line. 75 km of the traditional narrow-gauge route was converted to standard-gauge, but the rest of route was converted to the mixture of narrow-gauge and standard-gauge to cope with the conventional freight and passenger rail traffic. The maximum speed on the Akita Shinkansen is limited to 130 km/h, but travel time between Tokyo and Akita is cut by 40 minutes by eliminating the train change at Morioka Station and by raising the maximum speed on the Tohoku Shinkansen from 240 km/h to 275 km/h. (JR-East[32], 1997)

The travel time between Tokyo and Akita is 3 hour 49 minute in 1997, reduced 1 hour 17 minute from 5 hour 6 minute in 1987. (JR-East[33], 1997)

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[30] Source: *Tetsudo Journal* (Railway Journal) (1997): June,pp.30-36 (in Japanese)

[31] Source: JR-East (1997), "Keiei no Genjo to Kadai" (State of management and problems), July (in Japanese)

[32] Source:JR-East (1997), "Akita Shinkansen Opened 22 March", *Japan Railway & Transport Review*, April, pp.66

[33] Ibid. 31

2.1.9 *Nagano "Full" Shinkansen*

Nagano Shinkansen line, which is one of the five Seibi Shinkansen lines and the newest Shinkansen line implemented, started commercial service in October 1997. It connects Nagano and Takasaki, an existing station of Joetsu Shinkansen line. The length is 117km and all the trains run between Nagano and Tokyo, directly through on the Joetsu Shinkansen line. The construction began in 1989 between Takasaki and Karuizawa, and in 1991 between Karuizawa and Nagano. This is the first "Full" type Shinkansen constructed after the privatization of JNR except 3.6 km between Ueno and Tokyo in 1991. It was originally planned as a part of Hokuriku Shinkansen line of the Seibi Shinkansen Act, but it began partial operations in October 1997 to cope with the high travel demand expected for the winter Olympic games held in Nagano region in 1998.

The main reason why Full size Shinkansen was selected and new right-of-way was built on this route was the existence of very steep gradient on Yokokawa Toge (mountain pass). Its grade was 6.6% and trains required the help of an auxiliary engine on this gradient. It took considerable time to couple and uncouple an auxiliary engine at the both ends of the mountain pass, and elimination of this work was expected as a major time-saving component. Instead, the new route for Nagano Shinkansen has continuous 3.0% grade for 22 km long. The mountainous terrain en route required the digging of many tunnels and raised its construction cost significantly. After the Nagano Shinkansen started its revenue service, this segment of conventional narrow-gauge route ended its service. Mainly due to the small travel demand en route, the remaining parallel railroad of narrow gauge was separated from JR-East and now is operated by a different company subsidized by local governments. However, there was originally no freight rail traffic en route due to the steep gradient, and the compatibility between freight trains was not the issue in the Nagano Shinkansen case.

All trains run directly from Tokyo through on Joetsu Shinkansen route to Takasaki and go to Nagano. Since Nagano Shinkansen was constructed as a Full Shinkansen, it can run at the maximum speed of 260 km/h. The travel time between Tokyo and Nagano is 1 hour 19 minute in 1997, 1 hour 46 minute reduction from 3 hour 5 minute in 1987. (JR-East[34], 1997)

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[34] Ibid. 31

Figure 2-3: Akita Shinkansen[35]

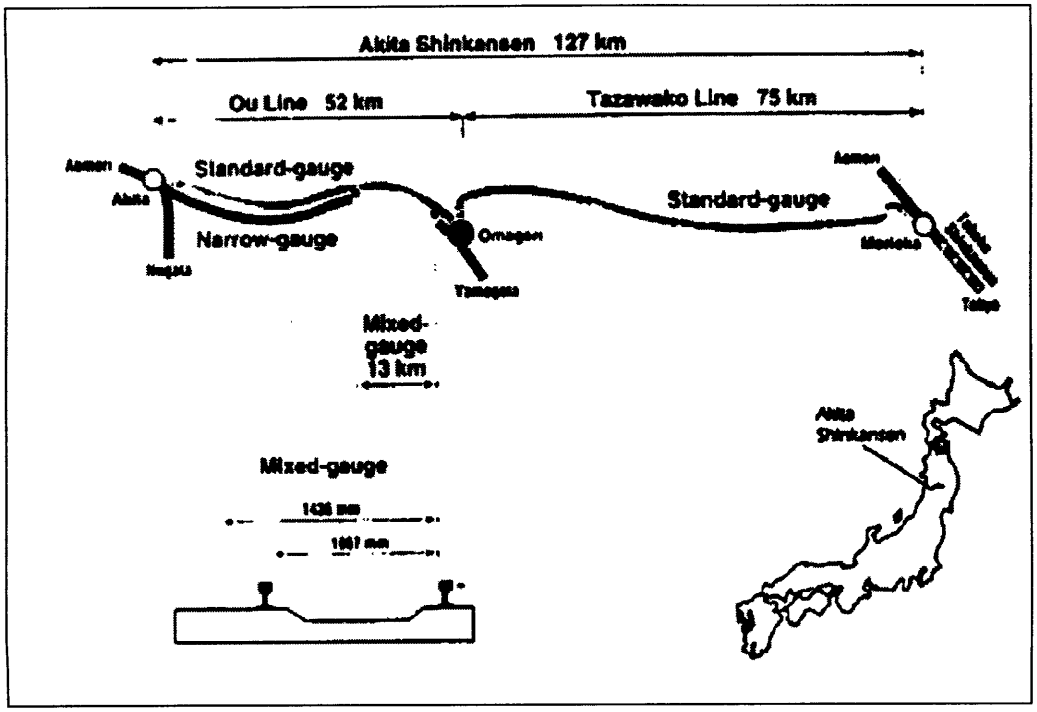
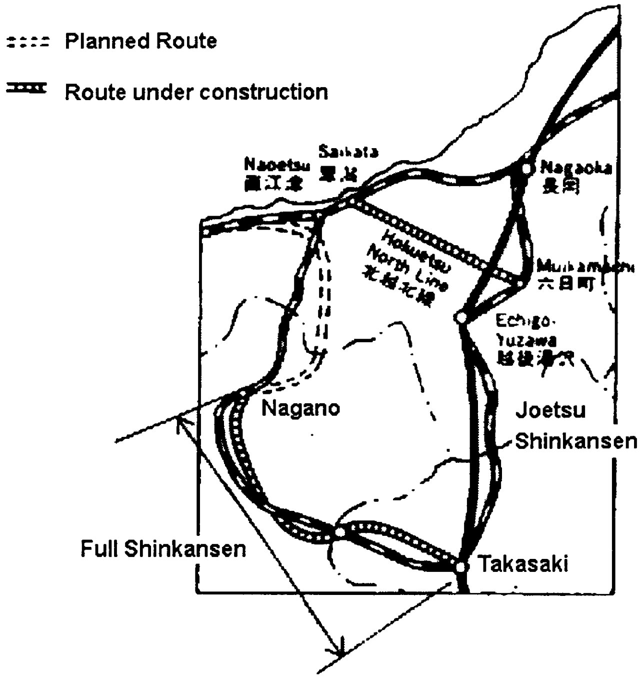


Figure 2-4: Nagano (Hokuriku) Shinkansen[36]



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[35] Source: *Japan Railway & Transport Review*(1997) No.11 pp.66

[36] Source: JR-East (1997),"Outline of Hokuriku Shinkansen"

2.1.10 *Maglev*

Maglev is a high speed ground transportation (HSGT) mode, and refers to the magnetic levitation and propulsion of trains with no physical contact with guideway while in high-speed operation. The vehicle is propelled by mutual attraction and repulsion of magnets. The on-board superconducting magnets constitute a linear synchronous motor. As the ground coils installed in the guideway receive the alternating current, a shifting magnetic field is generated along ground coils.(Taniguchi[37], 1992) This configuration eliminates the need for wheels and many other mechanical parts, thereby minimizing resistance and permitting excellent acceleration, with cruising speeds on the order of 300 mph or more.[38] There are two types of Maglev theoretically; electromagnetic system, or EMS, commonly referred to as an "attractive" Maglev system and electrodynamic system, or EDS, commonly referred to as a "repulsive" Maglev system. The Japan's Maglev is EDS type, while the German system is EMS.

Although no commercial high-speed operation of Maglev has been realized in the world, technological tasks are said to have been almost accomplished. The Japan's Railway Technical Research Institute,(RTRI) which performs the research and development of Japanese Maglev, published the following in 1997:

> *The RTRI started research of Maglev in 1970. One main development aim of RTRI is the enhancement of reliability and durability of the superconducting magnet (SCM). The SCM suffers from external magnetic disturbances caused by ground coils and from mechanical vibrations generated by vehicle dynamics; these disturbances cause quenching troubles, or the sudden disappearance of magnetomotive force of the SCM. We have studied these problems through many tests and studies, and have developed countermeasures... A land mark for Maglev occurred in 1990 when it gained the status of a nationally-funded project. The Minister of Transport authorized construction of the Yamanashi Maglev Test Line, targeting the final confirmation of Maglev for practical use. The new test line opened in April 1997 and is now being used to perform running tests in Yamanashi Prefecture. (RTRI[39], 1997)*

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[37] Taniguchi, Mamoru(1992), "High Speed Rail in Japan: A Review and Evaluation of Magnetic Levitation Trains", Working paper of University of California, Berkeley, Institute of Urban and Regional Development);No.561

[38] U.S. DOT(1997), "High-Speed Ground Transportation for America", FRA, September, pp.0-4

[39] Source: RTRI(1997): *http://www.rtri.or.jp/rd/maglev/html/english/maglev_frame_E.html*

The current speed record of 550 km/h by the Japanese Maglev (unmanned) was established on December 24, 1997 (531 km/h at manned on December 12, 1997). The RTRI and JR Central, the operational organization of the future Maglev between Tokyo and Osaka, announced that the problems of noise and magnetic field have been almost solved. They point out that the highest amount of magnetic field in vehicle is 10 gauss, which is lower than 20 gauss of standard. So the impact of strong magnetic field on the human body may be negligible. The noise level along the route is 46 decibel at the speed of 300 km/h, which is lower than 70 decibel of the governmental regulation.[40]

However, Maglev is still in the experimental and planning stage, and there remains issue of cost and maintenance. If both of the technological and financial problems be solved, it may be built between Tokyo, Nagoya and Osaka but on a different route from the Tokaido Shinkansen line. The project is called as "Chuo Linear" Maglev project and planned to alleviate the saturation of Tokaido Shinkansen line and air and highway congestion between Tokyo and Osaka. Its planned travel time between Tokyo and Osaka is just one hour, which means the average speed will be 500 km/h. If Chuo Linear Maglev be implemented, the Yamanashi Test Line will be used as a part of it.

2.1.11 *Conclusion*

It can be said the Japanese high-speed rail systems have made a fair success. High population density and saturated air and highway network in the metropolitan areas have worked favorably toward HSR and even an implementation of Maglev has been considered seriously. However, the magnitude of success depends on the specific corridors and less populated corridors have disadvantages for project feasibility. It is also noted that the concentration to metropolitan area is obvious in Japan and travel demand to Tokyo or Osaka metropolitan area is much higher than to other regions. Only the most successful Tokaido Shinkansen line has high travel demand on throughout the route but all other routes show high demand only in the metropolitan area and the farther a train goes from the metropolitan area, the less ridership it gains. This is also the underlying idea of Mini Shinkansen concept, which put emphasis on direct connection to Tokyo.

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[40] Source: *Kotsu Shinbun*(1997), Nov.5, pp.2 (in Japanese)

2.2 Europe

European countries have implemented high-speed rail systems beginning in the 1970s. High-speed travel is an excellent solution for Europe because of the relatively short distances between its national capitals (from 200 km to 1,000 km, equivalent to a maximum travel time of only 4 to 5 hours during the day per TGV or ICE). (Nijkamp[41], 1993) France, Germany, Sweden, Italy, Spain, and Switzerland have implemented their HSR systems. France and Germany can be regarded as the representatives of the longer history and technology, although their approaches to high-speed rail are not identical. In this section, these two different systems are briefly introduced, and then the concept of the European high-speed network is reviewed. The impacts of European high-speed rail are discussed in the next Chapter 3.

2.2.1 France

The French *Train a Grande Vitesse* (TGV) began operations in 1981 with the opening of the Sud-Est (South-East) line connecting Paris and Lyon. TGV-Atlantique (Atlantic) was added in 1989 with operations from Paris to Le Mans, and the TGV-Nord line between Paris and Lille started services in 1993. As of 1996, 1,280 km of the TGV route was in service, along lines that primarily radiate out from Paris to other parts of France. (Cervero[42], 1996) An additional 640 km of the TGV are in planning and construction, while another 1,400 km of new lines are under study. (Cervero[43], 1996)

TGV is a partly-dedicated system; its trains run at very high-speed on the dedicated sections near Paris and return to upgraded conventional tracks with other type of trains. The advantage of TGV compared to Japan's Shinkansen is that the width of gauge of new lines is the same as the existing railroad so that new TGV trains can utilize the conventional track with less modification. It is also noted that France has less mountainous regions than Japan. Geographically, the route runs through flat territory so that there are fewer curves on the route. For example, all

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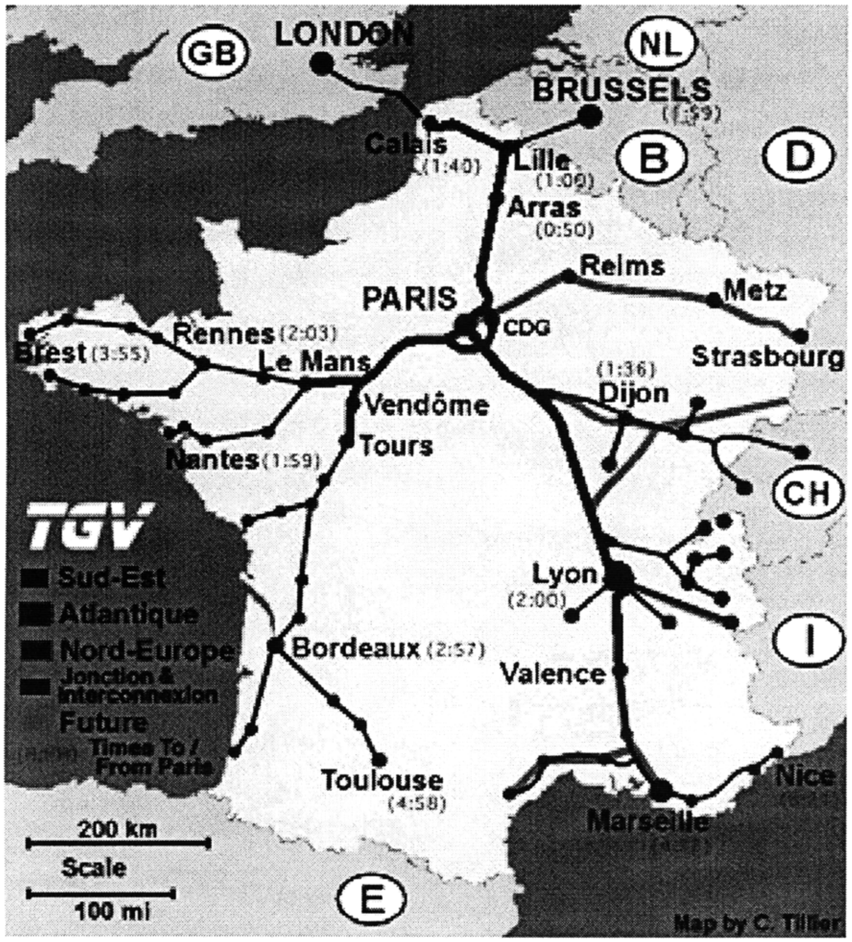
[41] Nijkamp, P. and Vleugel, J.(1993), "Success Factors for High Speed Rail Networks in Europe", *International Journal of Transport Economics*, October, vol.Xx-No.3, pp.255-270

[42] Cervero, R., Bernick, M. (1996). "High-Speed Rail and Development of California's Central Valley: *Comparative Lessons and Public Policy Considerations*", Working paper of University of California, Berkeley, Institute of Urban and Regional Development);No.675

[43] Ibid. 42

curve radii on TGV-SE are over 4,000 meters and 4,500 meters for TGV-A except for the run around Tours, which has a radius of 3,250 meters. This made it easy to expand TGV network throughout France economically. Each of three existing TGV lines, TGV Sud Est, TGV Atlantique, and TGV Nord are briefly introduced.

Figure 2-5: TGV Network[44]



2.2.1.1 TGV-SE

TGV Sud-Est (South-East) line was constructed between Paris and Lyon and started its service in 1981. Before the construction of TGV, this most important transport path in France was truly one of saturation and has produced a rail traffic condition for which a separate high speed pas-

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[44] Source: *http://mercurio.iet.unipi.it/tgv/map.html*

senger train line offers the only practical solution. (Strohl[45],1993) He summarized the importance of this corridor as follows;

> *There was never any doubt about the genuine necessity for the first TGV line in France. It arose out of the traffic saturation of the Paris-Lyon rail artery. This, the most important transport path in France, runs from Paris to Marseille via Lyon... The recorded use of this path, La Route Impériale, goes back to the time of Caesar, the emperor of Rome... About 40% of the French population is located along this path.*

TGV Sud-Est line connects the two strongest economic regions of France, Paris and the Rhone-Alps region. Between Paris and Lyon is a 386.4 km length corridor and the maximum speed of trains is 270 km/h. Like the Japanese Tokaido Shinkansen line, this TGV-SE has been an ideal route for a high speed line and has made a great success. Total rail passengers on the corridor increased from 12.5 million in 1980 to 22.9 million in 1992, 18.9 million being TGV passengers. (Vickerman[46],1997) For every 100 francs of income, operation costs take 38.8 francs, 23.1 francs go to paying infrastructure and rolling stock costs, and 39.1 francs go as a net profit to SNCF. (Strohl[47],1993) It is noted that the largest increase in ridership after the introduction of high-speed rail services between Paris and Lyon was in business journeys related to the sale or purchase of services. While total business journeys increased 56 percent, those related to the trade of services jumped by 112 percent.(Sands[48], 1993) It has to some extent the character of a long distance commuter line, which means that many daily return trips have been made by businessmen between two large cities. (Vickerman[49],1997)

It is noted that many efforts are made to reduce construction cost. For example, the maximum grades of the line is set to 3.5% to permit far less costly engineering work; it has allowed for a much more direct route to Lyon than the conventional route via Dijon. Furthermore, no tunnels and very few valley-spanning viaducts were made. (Strohl[50],1993)

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[45] Ibid. 7, pp.74
[46] Ibid. 4
[47] Ibid. 7, pp.83
[48] Ibid. 2
[49] Ibid. 4
[50] Ibid. 7, pp.76

2.2.1.2 TGV-Atlantique

The success of TGV Sud-Est in terms of both traffic and revenue generation confirmed the French view that high-speed rail was an appropriate solution and this led to an early decision in favor of TGV-Atlantique.

TGV-Atlantique was the second TGV system in France, connecting Paris and Le Man and Tours. The trains run at the maximum speed of 300 km/h and also have a world's record for the fastest travel by a steel-wheel on steel-rail train: 513.3 km/h, recorded near the new Vendôme station in 1990. The networks for which TGV-A service was contemplated carry about 20% of the SNCF traffic. (Strohl[51],1993)

2.2.1.3 TGV Nord

TGV Nord was planned as a direct access between Paris and London through the Channel Tunnel from the early 1970s, but this plan was halted once when the British government stopped the construction of the tunnel in 1975. Following an agreement between the British and French governments to build the Channel Tunnel in 1986, the French government confirmed the decision to go ahead with TGV Nord, initially to provide an improved Paris-Lille link (reducing journey times from over 2 hours to just 1 hour), but also to provide a through link to the Tunnel (and hence London) and to improve Paris-Brussels. The route length of the French portion is 333.1 km. Lille became a hub terminal of three sets of trains; Paris-London, Paris-Brussels, London-Brussels and economic development has been expected.

2.2.2 Germany

The German InterCity Express (ICE) began operating in 1991, and two separate lines are currently in operation: Mannheim to Stuttgart and Hannover to Würzburg. In addition, two lines are being planned: Hannover to Berlin for completion in 1998 and Köln to Frankfurt am Main in 2000. While French TGV aims at nationwide radial network of high-speed rail expanding from Paris, the construction of ICE aims at dealing with particular bottlenecks in the existing network so that all ICE lines are not connected to each other. (See Figure 2-6) The urban structure of Germany lacks the monocentric focus of France or Japan.

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[51] Ibid. 7, pp.84

Like the TGV, the ICE runs partly on newly-built right-of-way and partly on upgraded tracks. Trains run on upgraded tracks at the speed of 200 km/h. However, it is noted that the newly-built ICE right-of-way is not dedicated to high-speed passenger trains. It is designed for multi-purpose use, by the very high speed ICE trains at 250 km/h, by traditional IC trains running at 200 km/h and by freight trains running at lower speeds, but requiring more expensive engineering. (Vickerman[52], 1997) In the first five years of operation ICE passengers more than doubled from just over 10 million to nearly 23 million and ICE traffic accounts for 28 % long-distance passenger revenues. (Vickerman[53], 1997)

Germany has also been developing Transrapid, a Maglev system, and the congress has approved its construction between Hamburg and Berlin, 292 km long. This magnetic levitation system will be driven by long stator drive and will need totally new dedicated infrastructure. The technological difference between the Japanese Maglev is that its guideway acts as the motor system for a train. The scheduled date of completion is 2005, but there remain many financial and technical problems. (Vickerman[54], 1997)

2.2.3 European Network

The European countries are showing increasingly signs of an integrated economy, in which trade barriers are more and more removed and spatial interactions are increasing. The full exploitation of a nation's competitive advantage in an open international economic system has long been recognized as an important key force for maximizing national economic growth. (Nijkamp[55], 1993) High-speed travel on rail is an excellent solution for many of the passenger transport problems in Europe because the distance between the major cities range from 200 km to 1,000 km, distances for which the rapid train is very competitive.(Nijkamp[56],1993) The European Union (EC) has agreed to promote the integrated high-speed transportation network and the network of high-speed rail is one of the significant issues. Conscious of this challenge, the

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[52] Ibid. 4
[53] Ibid. 4
[54] Ibid. 4
[55] Ibid. 41
[56] Ibid. 41

Community of European Railway Companies of the twelve EC members plus Austria and Switzerland presented a project for a European high speed network in 1989. (Nijkamp[57], 1993)

The European countries have recently agreed to develop high-speed rail as not simple aggregation of nation-specific systems but an integrated transportation network. This "network" is essentially the linking together of a series of national plans for upgraded or very high speed rail improvements which emerged during the 1970s and 1980s.(Vickerman[58], 1997) The Eurostar which started its operation recently from London to Paris or Brussels through the Channel Tunnel would be the first implementation of European high-speed rail concept. Although the upgrading infrastructure in the British part has not completed, a direct "ski Eurostar" service also started between London and Alps region directly in the winter of 1997.

At present, however, the Eurostar is the only example of integrated European HSR network. Vickerman[59] noted the present status of this integrated network as follows:

> *... the only really planned network is the so-called (now rather inaccurately) TGV-North European, also known as the PBKAL (Paris-Brussels-Köln-Amsterdam-London). Increased interest is now being shown in the (genuinely) Northern European network using the various fixed links proposed between Scandinavia and continental Europe linking Germany, Denmark, Sweden and Norway. These two networks are, however, in very different geographical and economic situations and need to be distinguished from each other.*

2.2.4 Summary

In addition to the high-speed rail technologies discussed here, Spain and Sweden also have their own HSR systems. It might be safe to say that the integration of HSR networks in Europe will continue, although there remains several issues to be solved. We will discuss the impacts of HSR on the European region in the following Chapter 3.

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[57] Ibid. 41
[58] Ibid. 4
[59] Ibid. 4

Figure 2-6: ICE Network[60]

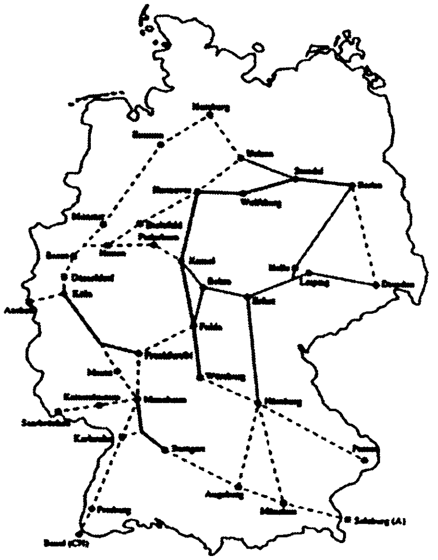
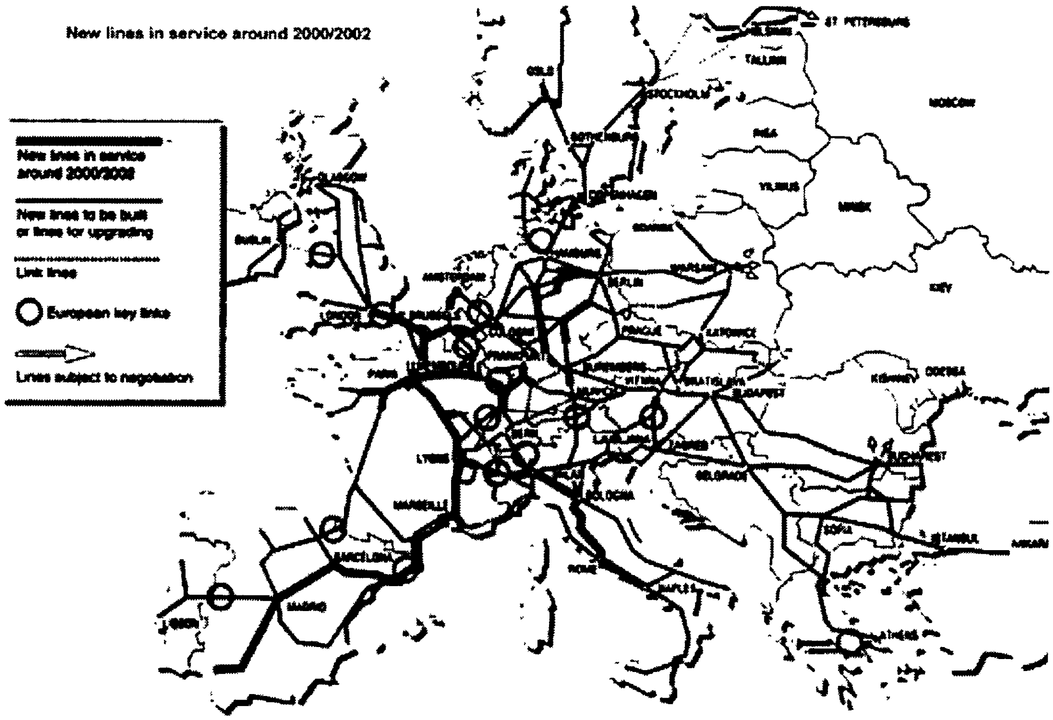


Fig. 4. German high-speed rail routes for the year 2010 ——— Neubaustrecke in service or confirmed. ------ Additional 'Unification' routes studied. . . . . Other NBS/ABS routes

Figure 2-7: European High-Speed Network[61]



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[60] Source: Ibid. 4

[61] Source: Korpanec(1996), *Japan Railway & Transport Review*, March pp.21

2.3 United States

While there have been many studies and proposals of high-speed rail (HSR) over the past dozen years in many regions of the North American continent, it has been most difficult to advance beyond the planning phase. (Sullivan[62], 1992) The difficulties mainly come with the lack of profitability of various projects, historic policy bias toward rail compared to highway system, and environmental concerns. However, increasing congestion on interstate highways and airports in the U.S. would have made a high-speed rail more attractive to large portions of the population.

Many empirical studies suggested that a HSR in the U.S. could be technically feasible, and could cover operating costs in some corridors, but it could not cover all the capital cost in a reasonable period. (Sullivan[63],1992) Therefore, reduction of construction cost has been a key issue to realize high-speed passenger rail in the U.S.

It is generally perceived that the only high-speed rail implemented currently in the U.S. is the incremental high-speed passenger rail service through the North-East Corridor from Washington D.C. to New York City. An incremental high-speed rail is defined as a high-speed and high-quality passenger rail service that utilizes existing railroad infrastructure to share the right-of-way with slower freight trains or commuter trains. The major advantage of this concept is its lower construction cost, and passenger trains will be operated at speeds of between 110 and 150 mph with frequencies significantly higher than those currently offered by National Railroad Passenger Corporation (Amtrak) services. (Roth[64],1994)

Part of the Northeast corridor, between Washington D.C. and New York City, is currently operated up to 125 mph and provide frequent service (about twice per hour.) These express trains have led fair success in attracting passengers from the air and highway mode so that Amtrak is now planning to extend this incremental HSR service from New York City to Boston via New Haven. This service will start in 1999, and is expected to reduce congestion on the parallel highway and at the airports.

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[62] Sullivan, Dennis F(1992), “High-Speed Rail in North America”, *Rail International*, June-July
[63] Ibid. 62
[64] Roth, Daniel, L(1994), “Incremental High Speed Rail in the U.S.: Economic and Institutional Issues”, Master’s Thesis, Massachusetts Institute of Technology

However, with its lower construction cost, an incremental HSR has several issues to be solved, which do not apply to a conventional high-speed rail with dedicated right-of-way. Firstly, the existence of grade crossings has caused concerns for the safety of incremental HSR. The possibility of accidents at grade crossing has been a significant problem for any rail operation; as the train speed increases, the seriousness of accidents at grade crossing may increase, although it may not be a linear increase. In fact, all grade crossings were removed on the New York - Washington corridor where Amtrak operates at speeds up to 125 mph, during the Northeast Corridor Improvement Project (NECIP) since the late 1970's. (Roth[65], 1994) Installing advanced grade protection systems such as trapped-vehicle detection system can be another solution to this problem. Although both options are technically feasible, they will increase the infrastructure cost and may negate the advantage of incremental HSR to some extent.

The other problem comes with the line capacity. Since an incremental HSR allows different types of train running at different speed on a shared right-of-way, it may require additional infrastructure such as passing sidings. For example, a fast train will at times overtake a slow one and when this occurs, in order to let the faster (and presumably higher priority) train pass, the leading train must enter a passing siding. (Roth[66], 1994) Also on single-track mainlines, which are not uncommon in the U.S., the train schedules are constrained by the need to coordinate the meeting of opposing traffic at two-track sections installed for that purpose. In both cases, the addition or lengthening of passing sidings may be required to accommodate the additional meets generated by the high-speed passenger service. This will become a major problem for higher speed and higher frequency passenger train operation, in that it will be extremely difficult to develop a working schedule that does not cause delays for passenger trains.

It is noted that freight railroads, which generally own the rights-of-way in the U.S., do not receive any operative benefits from this project. Rather, they will suffer from the slower speed of freight traffic and complicated operating practice. For example, passing by faster passenger trains will delay the movement of freight trains. In addition, the features of high-speed and high-frequency passenger service will make the operating practice of conventional freight railroads much more complicated and may require an advanced train control or dispatching system.

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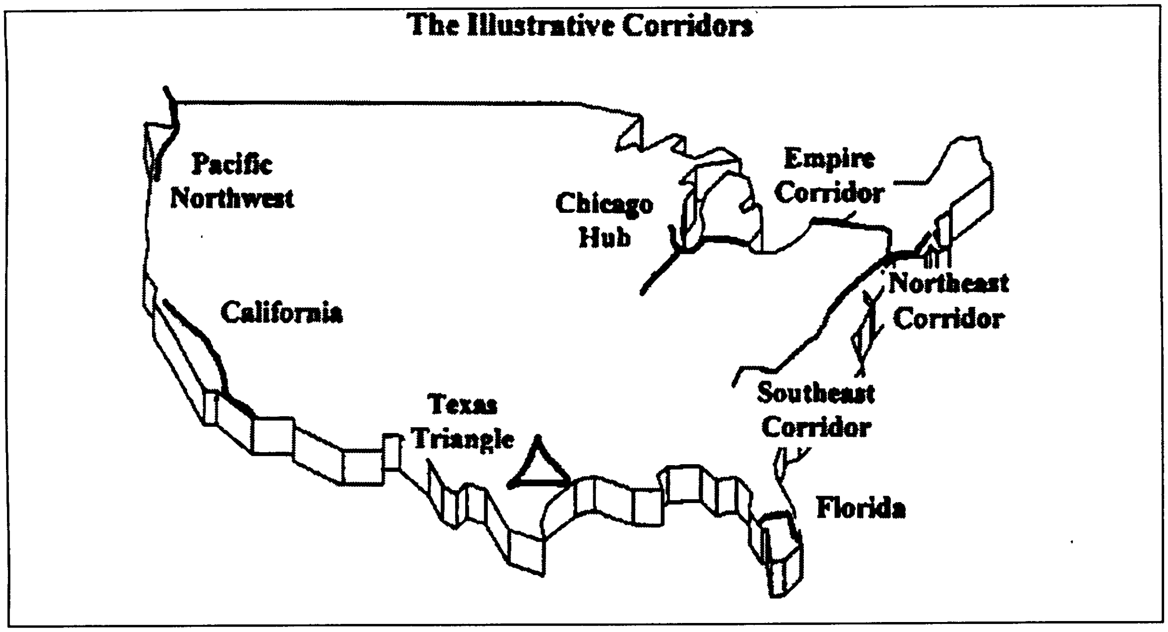
[65] Ibid. 64

[66] Ibid. 64

It is also noted that the liability issue in case of accident has been a great concern for freight railroads since a high-speed operation would result in more serious outcome when collision occurs. Financially, the loss of life is much expensive than loss of freight, and this risk cannot be negligible.

Thus it can be easily understood that freight railroads will generally oppose, or at least have minimal enthusiasm toward the implementation of incremental high-speed rail. It is noted that the most of rights-of-way between New York City and Boston were owned by Amtrak itself, and the small number of conflicts with freight railroads has been a key for its successful implementation.

Figure 2-8: U.S Incremental High-Speed Rail[67]



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[67] Source: USDOT(1997), “High-Speed Ground Transportation for America”, FRA, September, o-12

2.4 Conclusion

In this chapter, the current technologies of high-speed rail in Japan, Europe and the United States were discussed. In Japan and Europe, further construction of high-speed rail is likely to occur, while in the U.S., it might depend on the magnitude of success in the Northeast Corridor project between New York and Boston. In the next chapter, we review literature about high-speed rail to understand the current discussion of high-speed rail and regional economic development.

3. Literature Review of High-Speed Rail Impacts on Regions

In this chapter, several empirical studies are reviewed to consider the relationship between high-speed rail and regional economic development. This review includes literature of the relationship between general transportation infrastructure and economic development, analyses that have classified benefits of HSR, and several case studies of specific high-speed rail projects. Some of the qualitative studies providing analytical perspectives are reviewed as well as quantitative studies, because it is important to understand the impacts of HSR both quantitatively and qualitatively.

3.1 Transportation Infrastructure and Economy Growth

Firstly, several previous research efforts on the relationship between public transportation infrastructure investment and economic growth are reviewed.

3.1.1 Quantitative Aggregate Analysis

The impact of public infrastructure investments on economy has been researched by many authors. To find the relationship between public investments and the national economy, Aschauer[68] (1989) used an aggregate production function to estimate the elasticity of output per unit of private capital with respect to public capital per unit of private capital and used aggregate time-series data of private output and the stock of non-military public capital. He modeled the output per unit of private capital as a function of time, labor per unit of private capital, public capital per unit of private capital, and the level of capacity utilization in manufacturing. According to his study, the elasticity of private capital output with respect to public capital investment was 0.39 between 1949 and 1985, and he argued that most of this effect is from "core infrastructure", such as highways and streets, water and sewer facilities, gas, electric, and transit facilities. His result means 1% increase in public infrastructure investment has resulted in a 0.39% increase in private productivity. However, this is much higher than generally perceived, and even higher than typical rate of return for a private capital investment, and the plausibility of his research was challenged.

Also Munnel[69](1990) estimated the national-level elasticity of output per hour with respect to public capital by modeling private non-farm business output per hour as a constant returns-to-scale function of the technology level, private capital services per hour of labor, non-military public capital stock per hour of labor, and the level of capacity utilization in manufacturing. Although the model she used was different with Aschauer's, she found the elasticity between 0.31 and 0.37, which is very close to the Aschauer's result.

These two national-level analyses, however, resulted in extensive debates on whether those values are plausible. The majority were doubtful, because their results imply that the public investment have obtained higher rate of return than private investment, which is not likely the case. Generally speaking, private investment would be more effective in raising the productivity of firms than public infrastructure investments such as transportation, because the role of public investments on economic growth is to assist private sectors. It is also noted that the statistical analyses do not guarantee the causal relationship between the public infrastructure investments and private sector economic growth; other factors might exist that influenced both of them.

Several efforts have been made not only at national level but also at the regional level, to estimate the impact of infrastructure investment on regional economy. The majority have implied that the estimated elasticity of output with respect to public capital tended to be smaller than the national level. Munnel[70](1990) found that the elasticity between public infrastructure investment and public capital stock was between 0.06 to 0.15 at state level, depending on whether a constant return-to-scale constraint was applied or not. This result of lower elasticity on state level can be explained by the fact that the impacts of a regional infrastructure investment is not limited to inside the region; for example, highway infrastructure investment in a region is beneficial not only in the region, but also in neighboring regions connected by the highway.

These studies by Ashauer and Munnel discussed non-military public infrastructure investments, but they also included investments other than for transportation, such as water systems. To

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[68] Aschauer, David Alan (1989), "Is Public Expenditure Productive?" *Journal of Monetary Economics* 23, 177-200

[69] Munnell, Alicia, H(1990), "Why Has Productivity Growth Declined? Productivity and Public Investment" *New England Economic Review* 3

[70] Munnell, Alicia H et al.(1990), "How Does Public Infrastructure Affect Regional Economic Performance?" *New England Economic Review*,11

estimate the impact of public transportation investments, Munnel[71](1990) divided public capital into three components: highways and streets, water and sewer systems, and others to divide the impacts of public investment by its purpose. She found the elasticity of investments to highways and streets at national level as 0.06. Also at state level, Garcia-Mila and McGuire[72](1992) modeled highway capital and education expenditures in a Cobb-Douglas production function with gross state product as the dependent variable. They found the elasticity of gross state product with respect to highway capital was 0.04.

Recently Nadiri and Mamuneas[73](1996) estimated that the elasticity of output with respect to total highway capital at national level. They estimated cost and demand function for each industry and decomposed "Total Factor Productivity" (TFP) growth. They analyzed the impact of U.S. highway capital investment on national economy at industry-level and used the data covering the entire U.S. economy for the period 1947 - 1989. They concluded that total highway capital and non-local highway system (NLS) capital contribute significantly to the economic growth and productivity at both the industry-level and national-level. The magnitude of the elasticity of output with respect to total highway capital at the aggregate level is about 0.05.

In summary, the positive impacts of public infrastructure investments on private economy has been examined by several studies; it is smaller than that of private capital investments. The studies reviewed here have shown that the impact of public transportation infrastructure investments on economy is about 5% of elasticity, which means 1% increase in public transportation investment will result in 0.05% increase in productivity of private firms.

It is noted that these analyses limit their study only in the U.S. In addition, none of the previous aggregate studies of productivity and infrastructure investment have attempted to isolate the impact of passenger rail transportation investment on economy. We also note that there have been no aggregate level research in terms of the impact of high speed rail on regional economic development. It is not surprising, because at national level analysis, there is no country which has extensive network of high-speed rail enough to compare with other public investment such as the highway network. Other possible reason would be the data availability. For the U.S., simply

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[71] Ibid. 70

[72] Garcia-Mila, Teresa, and McGuire, Therese J.(1992), "The Contribution of Publicly Provided Inputs to State's Economies" *Regional Science and Urban Ecnomics*,22

there is not enough HSR implementation while in other countries it is very hard to get the reliable data. So analysis of HSR impact on regional development tend to be more qualitative and discussions often remain less quantitative when compared with the highway network.

3.1.2 Qualitative Analysis

Due to the lack of quantitative analyses, much efforts have been done to analyze the impact of HSR on regions qualitatively. These studies mainly aimed to introduce perspectives to understand the benefits of HSR. Here we introduce two important concepts.

Firstly, we discuss the idea of two different impacts of HSR; re-distributive effects and generative effects. A region generally tries to attract more capital investments and people in order to develop. In this context, new transportation facilities can have two different effects on development: (1) re-distributive effects whereby development that would have occurred anyway is relocated to take advantage of the new facility, (2) generative effects that arise from utilizing previously unused local resources or using resources more efficiently. (Rephan,1993[74])

(1) Re-distributive Effects

Re-distributive effects of the infrastructure investment may not be the national goal since the relocation of firms or households itself is just a transfer from one region to another region. However, redistribution effect itself can be a regional goal; a remote (and presumably less economically developed) region will set it as a goal to pursue equity among regions when it regards transportation infrastructure as a tool to raise accessibility and to catch up with other regions. The underlining idea is that improving accessibility of regions will increase regional competitiveness.

However, in terms of high-speed rail, several analyses warned that this idea may not be the case. For example, Nakamura and Ueda[75](1989) argued that the larger cities that have already enjoyed

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[73] Nadiri, M. Ishaq, and Mamuneas, Theofanis P.(1996), "Highway Capital and Productivity Growth", quoted from Madrick, Jeffery (1996), "Economic Returns from Transportation Investment"

[74] Rephann(1993), "Highway Investment and Regional Economic Development: Decision Methods and Empirical Foundations", *Urban Studies* 30(2)

[75] Nakamura, H. and Ueda, T(1989), "The Impact of Shinkansen on Regional Development", Proceeding of 5th WCTR

concentration in the region will get the more benefits from HSR. On the other hand, Sasaki et al.[76](1997) evaluated the impacts of HSR on spatial dispersion of economic activities and population by defining accessibility functions. They constructed a supply-oriented regional econometric model and made simulation analyses for hypothetical scenarios of Shinkansen network. They concluded that HSR network expansion leads to regional dispersion to some extent from the developed regions, but the degree of dispersion cannot be much increased by further construction of network. In addition, they argued that when HSR connects a developed region and undeveloped region, the accumulation of existing transportation network in the developed regions might help accelerating further concentration into developed regions.

It is noted that construction itself will have impacts on regional economy, although it is also a transfer effect on national level.

<u>(2) Generative Effects</u>

Transportation infrastructure can cause net economic growth if it lowers the production costs of firms so that activities from outside the region are attracted there or local enterprises enjoy a competitive advantage over business in other areas. (Huang,1994[77]) For example, if a public transportation infrastructure works as a "pure public good", it will increase the output of all firms through a neutral increase in efficiency and raise the productivity of private firms. However, it is also important to know whether specific public investment is a substitute or a complement to private input. If it is just a substitute for private investment, it will crowd out the private investment and the public investment will be wasted in a sense. If it is complementary, higher public investment may raise the marginal productivity of private capital and it may induce or crowd in the private investment. (Ashauer[78], 1989)

Plassard[79](1994) argued that a HSR may have impacts on economy only in the long run.

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[76] Sasaki, Komei, Ohashi, Tadahiro, Ando, Akio(1997), "High-speed rail transit impact on regional systems: does the *Shinkansen* contribute to dispersion?", *Annals of Regional Science*:31

[77] Huang, William S(1994), "Transit and Regional Economic Growth: A Review of the Literature", Working paper of University of California, Berkeley, Institute of Urban and Regional Development);No.647

[78] Aschauer, David, A(1989), "Does Public Capital Crowd Out Private Capital?", *Journal of Monetary Economics*, 24, pp.171-188

[79] Plassard, F. 1992. European Conference of Ministers of Transport, "Report of the Ninety-Fourth Round Table on Transport Economics: Regional Policy, Transport Networks and Communications", held in Paris on 5th-6th; November.

> *Belief in the existence of transport infrastructure effects is also based on the observation that considerable transformation in the organisation of space are detectable over very long periods... Insofar as it is increasingly difficult to justify the short- or medium-term infrastructual effects, the tendency is to return to their longer-term structuring power... Apart from the effects connected with the construction stage, transport infrastructures are thought to have no short-term effects, but to bring a reorganisation of space in the longer-term.*

His point is that transportation infrastructure can have a catalytic effect so that it can cause development, but itself is not sufficient to generate growth. Since causal relationship between transportation infrastructure and regional development is always like the "chicken and egg" problem, this statement seems to be reasonable.

Analytically, a high-speed rail train generally carries only passengers, while highway or a plane serves both passenger and freight. In other words, the number of people who receive direct benefit by a HSR investment is limited to passengers (especially business travelers) compared to highway or airport investment,.which will benefit a broader set of users. However, these days when many highways and airports are fairly congested, a HSR may have indirect impacts on economy in terms of congestion relief, cleaner air, energy saving and so on. In other words, it can reduce the costs of using other modes by increasing HSR modal share; these can be counted as indirect benefits of HSR.

3.1.3 Summary

Although there is no concrete agreement about the magnitude of impact, we can say that to some extent transportation infrastructure investment has positive impact on national and regional economy both qualitatively and quantitatively. However, it is not guaranteed that public transportation infrastructure has greater impacts on economy than other investments, and other relevant policies must be implemented to develop the economy.

However, the difficulty for proving relationship quantitatively between transportation infrastructure and regional economic development leads to several case studies focusing rather qualitative aspects of development, for example, the change of land use patterns around HSR stations. It is also noted that the societal, geographical and political conditions would have great influences on the effectiveness of HSR, and case studies might be required to understand the impacts of any HSR projects in specific contexts.

3.2 Cost - Benefit Analysis (CBA)

Cost - Benefit Analysis is useful to decompose the fuzzy word of "regional benefits of HSR" into understandable sub-benefits that can be estimated quantitatively. It is noted that financial feasibility is a key issue in any transportation project, but a CBA can include other benefits outside the entity liable for operation as long as these benefits can be measurable in a quantitative way and with no double-counting.

The usefulness of CBA is widely approved, and currently it seems to be the only standard to judge the feasibility of HSR project. O'Connor et al.[80](1997) categorized rail and rail-related intermodal investments and made a model to estimate net present value and economic rate of return. They classified benefits into three categories: direct user benefits, indirect user benefits and non-user benefits. Martin[81](1997) confirmed that if the result of CBA is positive, the project may generate growth equal to the amount of the NPV.

However, every cost-benefit-analysis should be performed very carefully, because it is difficult to represent some of the benefits and costs in monetary terms. In addition, a CBA for high-speed rail is not a straightforward task because of the shared costs between transportation components and ambiguous boundary of transportation systems to bear costs. Levinson[82](1996) discussed this problem as follows:

> *Accounting difficulties arise because there are several shared costs. For example, travelers ride in vehicles (cars, planes, trains) that use infrastructure (roads, airports, tracks). One cannot simply add up the costs for each component. There are transfers between components, such as gas taxes used to fund infrastructure, and these transfers must be excluded from the final tally.*
>
> *Other problems arise when establishing transportation system boundaries. Automobiles typically burn gasoline and create pollution, which usually get charged to the car's account. A high-speed train uses electricity, creating pollution at the power plant. Should this pollution be ascribed to rail travel? Or should we say that the electricity sector is responsible for mitigating its own pollution and that those mitigation costs should be reflected in higher electricity costs borne by the railroad?*

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[80] O'Connor, Michael, J, Harvey, Jonathan, M, Moore, Jack, M(1997), "*RailDec*: A Decision Support Tool for Rail and Rail-related Investments", TRB 1997 Annual Meeting Preprint, No.971395

[81] Martin, Fernand(1997), "Justifying a high-speed rail project: social value vs. regional growth", *Annals of*
Sometimes it is hard to draw a generalized conclusion from a CBA because specific characteristics of a region might have significant impacts on each analysis. *Regional Science*: 31

[82] Levinson, David (1996), "The Full Cost of Intercity Travel: A Comparison of Air, Highway, and High-Speed Rail", *Access*, Number 9, Fall 1996

Transportation costs will change when the number of users increases or decreases. The more people sharing a fixed cost, the lower the per-passenger cost, while the more people using a road, railroad, or airport, the greater the delay. Therefore properly measuring costs requires knowing how costs vary with use.(Levinson[83],1996) It should be noted that performing a CBA will need several assumptions (e.g. demand at specific level of service) and no unanimous agreement has been made on how to make estimate accurate. The methodologies used in CBA have varied.

It is also noted that pre-project CBA does not necessarily guarantee the actual impacts of HSR after implemented. For example, Rus and Inglada[84](1997) argued that *ex post* cost-benefit analysis of the Spanish high-speed link showed the introduction of HSR in 1987 was not justified in the chosen corridor.

We saw that a cost-benefit analysis seems the only one quantitative analysis that can be performed as a project evaluation. Here, benefit and cost components used in a traditional CBA are discussed.

3.2.1 Benefit Components

We start our discussion by the most recent research published by the Department of Transportation in 1997. The Federal Railroad Administration[85](1997) published feasibility research of the several U.S. corridors for high-speed ground transportation, and they classified the total benefits by a HSR into 3 categories to avoid double counting.

- **direct user benefits**
- **non-user benefits**
- **societal benefits**

If we define consumer surplus as "benefits that HSR users receive but do not pay for", the direct user benefits can be represented as summation of the system revenue and consumer surplus. Theoretically consumer surplus can include even qualitative benefits such as passenger conven-

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[83] Ibid. 82

[84] Rus, Ginés and Inglada, Vicente(1997), "Cost-benefit analysis of the high-speed train in Spain", *Annals of Regional Science*:31

[85] Ibid. 38

ience and comfort. They calculated the amount of consumer surplus by assuming travel demand at certain speed-level and fare level.

However, it is normally impossible to derive the amount of consumer surplus accurately because the estimation of demand at various level of service is very difficult. Rather, decomposition of above benefits has been often preferred to make analysis more accurate. For example, three benefits above can be subcategorized as follows:

- *direct user benefits*
    1. travel time savings
    2. passenger safety cost savings
    3. passenger convenience and comfort benefits
- *non-user benefits*
    4. highway congestion savings
    5. highway safety cost savings
    6. highway maintenance cost savings
    7. airport reduced congestion savings
- *societal benefits*
    8. environmental cost savings
    9. regional development

These nine benefits are explained in the following section.

3.2.1.1 Travel Time Savings

For most people who travel, the time en route is in some degree dead time in their lives, a brief period to be completed as quickly and with as little discomfort as possible. (Strohl[86], 1993) Several case studies shows that time-saving benefits are a very large part of the total benefits of HSR.

Shearin[87](1997) argued that "traditional" time-saving benefits dominate the public benefits, comprising 92 to 98 percent of total public benefit.

Travel time savings look relatively straightforward and easy to estimate. However, one has to estimate the number of travelers as a function of speed, which is not an easy question. Further,

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[86] Strohl, Mitchell, P.(1993), "Europe's High Speed Trains: A Study in Geo-Economics", pp.21

[87] Shearin, Gui (1997), "Methodology development for estimating external benefits and costs of high-speed ground transportation in the United States", Transportation Research Record, No.1584

monetary value of time may vary among travelers, depending on their trip purpose or on the region. Generally, the value of time is higher for business travelers.

It is noted that frequency of schedule of air and high-speed rail might influence the decisions of travelers. Air and high-speed rail, with their limited frequency of service, have schedule delays; automobile drivers can depart at any time. (Levinson[88],1996)

Access time at origin and final destination also affects the choice of modes by travelers. For example, the decision will be on a different basis if the final destination is Manhattan, New York or Los Angeles, California. If Manhattan, heavy road congestion in the area will favor high-speed rail, whose station is located in the downtown. In Los Angeles, however, one has to rent a car to reach the final destination when traveling by air or high-speed rail thus favoring automobiles.

3.2.1.2 Passenger Safety Cost Savings

High-speed rail systems are generally designed to reduce the possibility of accidents. Routes are entirely grade-separated and have other built-in safety features. The safety costs are thus capitalized in higher construction costs, rather than being realized in accidents. (Levinson[89], 1996) Since the possibility of accidents in HSR systems is very low, it is very hard to quantify the savings both for old and improved systems.

3.2.1.3 Passenger Convenience and Comfort Benefits

This represents benefits somewhat fuzzy and hard to measure quantitatively. However, it may be captured partially when careful analysis is done. For example, in-vehicle working capability on HSR trains or elimination of the need to change trains might be calculated as a special kind of time savings.

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[88] Ibid. 82

[89] Ibid. 82

3.2.1.4 Highway Congestion Savings

When HSR is successful and diverts many passengers from using automobile, the number of cars running on parallel highways will decrease and congestion on the highway would be eased. The benefits can be estimated in terms of the value to remaining highway users of travel time saved when traffic volumes on major highways connecting HSR travel corridors decrease (or grow at a reduced rate) and travel speeds improve. (Shearin[90], 1996)

3.2.1.5 Safety Cost Savings on Parallel Highway

Highway safety depends on the volume of traffic flow and if the number of cars decreases due to HSR and if the number of accidents also decreases, it can be counted as a benefit of HSR. To estimate the accident rate before and after HSR is necessary. However, there is a trade-off between safety and speed; if traffic volume grows significantly and travel speed is very low, the highway system would be safer in terms of less damage as a result of collisions. So it is difficult to capture this benefit quantitatively.

3.2.1.6 Highway Maintenance Cost Savings

If traffic volume on highway has decreased, it would cost less for the maintenance of highway infrastructure and can be calculated as a benefit of HSR. However, there also might be trade off; less traffic leads to higher speed, which will cause more damage on pavement, especially by heavy trucks.

3.2.1.7 Airport Congestion Savings

Many airports have recently reached operational capacity and delay occurs regularly. So diverting to HSR is beneficial to remaining passengers because of travel time savings. It can be calculated if the number of flights decreased by HSR is known. In addition, if the decrease of flights by the HSR allows increase of flights on other routes, the capacity of congested airport is better utilized for the entire transportation network.

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[90] Ibid. 87

3.2.1.8 Environmental Savings

A HSR is environmentally less harmful in terms of air pollution and energy consumption. However, it is hard to estimate the impact; it may be partially captured when emission savings are measured due to reduction of vehicles. However, it must be noted that HSR may cause other negative impacts on environment. Noise and vibration along the route might be a significant issue especially in the metropolitan area.

3.2.1.9 Regional Development

The following values are often claimed as benefits of high-speed rail. However, many of them are indirect and may lead to double-counting and therefore should be treated carefully in a cost-benefit analysis.

- population increase (result of other benefits)
- increase of gross regional product (may be result from other benefits)
- land price (may be a proxy of total benefits to the region)
- increase of tourism
- increase of income per capita
- increase of tax income
- Development around stations
- Construction itself (might be only transfer)

3.2.2 Cost Model

In the previous section, we discussed a traditional CBA. It is noted that there can be another approach to estimating the cost of HSR from institutional perspective. To decompose the total cost needed for implementation of HSR, a cost model for HSR was proposed by Phelan[91](1990). According to him, the cost of HSR can be decomposed into 3 parts: land acquisition cost, capital cost, and operating cost.

Total cost = land acquisition cost + capital cost + operating cost

$$\begin{aligned}
C_{tot} &= C_{acquis} + C_{const} + C_{oper} + C_{other} \\
C_{acquis} &= C_{land} + C_{roll} + C_{spec} \\
C_{const} &= (C_{gw} + C_{term} + C_{pow} + C_{misc})\,(F_{const/tech})(F_{const/site})(F_{const/fin\text{-}leg}) \\
C_{oper} &= C_{oper\text{-}pers} + C_{oper\text{-}sup} + C_{oper\text{-}maint}
\end{aligned}$$

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[91] Phelan, Randal S. (1990), "Construction and Maintenance Concerns for High Speed Maglev Transportation Systems", MST thesis, pp. 94

Where
C_{tot} = total cost of the high speed ground transportation system
C_{acquis} = cost for required acquisitions
C_{const} = cost of construction of the system
C_{oper} = cost of operational and maintenance of the system
C_{other} = feasibility study and design costs, plus financial and legal costs of the system, minus the salvage value of the system

C_{land} = cost of land needed for guideway, terminals, and power stations
C_{roll} = cost of trainset vehicles, or rolling stocks
C_{spec} = cost of special maintenance and emergency equipment

C_{gw} = cost of the guideway construction
C_{term} = cost for terminal facility construction
C_{pow} = cost of wayside power station construction
C_{misc} = cost of miscellaneous buildings and maintenance facilities

$F_{const/tech}$ = influence technological complexity has on construction costs
$F_{const/site}$ = influence site characteristics has on construction costs
$F_{const/fin\text{-}leg}$ = influence financial and legal requirements have on construction costs

$C_{oper\text{-}pers}$ = cost of operational staff and personnel
$C_{oper\text{-}sup}$ = supply costs for operations
$C_{oper\text{-}maint}$ = maintenance costs required for safe and continual system operation

However, this cost model does not include external costs such as environmental issues. Rather, this model might be more useful for financial purpose to check the feasibility of a project by the private sector.

3.2.3 Summary

We found that an extensive CBA needs much information including travel time savings and accurate demand estimation at improved level of service. In addition, in terms of components to represent the benefits and costs of high-speed rail, there is currently no standard methodology established with unanimous agreement. Performing an extensive CBA is a complicated task and it is beyond the scope of this thesis. We rather focus on the travel time saving as a major benefit of HSR in Chapter 4.

3.3 Case Studies for Specific HSR Projects

Here, we review several studies that have discussed impacts of specific HSR systems. Some of them performed cost-benefit analysis (CBA) to verify the feasibility of HSR project, since CBA is a fundamental methodology for project evaluation. We review empirical studies for three areas; Japan, Europe, and the U.S.

3.3.1 Japan

Sands[92](1993) and Cervero and Bernick[93](1996) thoroughly reviewed the state of the arts of HSR around the world. They looked into the change of land use around stations of both the Japanese Tokaido Shinkansen line. In their review of the Tokaido Shinkansen line, they focused on three new stations, Gifu-Hashima, Shin(New)-Yokohama, Shin-Osaka, which locate on the periphery of a city and could be excellent test cases for land-use impacts of the HSR. They quoted Amano and Nakagawa(1995)s' work that had argued: (1) Little new development occurred in central areas already well-served by inter-city rail transit. (i.e. Tokyo and Osaka station) These central areas are already developed, and marginal impacts of HSR may not be important. (2) Suburban HSR stations tended to siphon commercial development away from city center stations. Two new HSR stations located in the suburb of a metropolitan area, Shin-Yokohama and Shin-Osaka, have experienced considerable change of land use pattern and growth around the stations. It is seen that offices originally located in CBD have moved near to the new stations. However, the development of suburban HSR station is not guaranteed. (3) Gifu-Hashima station, which locates near the Nagoya metropolitan area, has failed to show development around the station. According to Amano and Nakagawa, the cause of less development around Gifu-Hashima station would be the lack of good conventional transit connections to the new HSR. They reached the conclusion that the Shinkansen line itself was not sufficient and active participation of local government in city planning has been necessary.

Ueda and Nakamura[94](1989) thoroughly investigated the impacts of the Tohoku Shinkansen line qualitatively and quantitatively. They found quantitatively that the Tohoku Shinkansen line had had positive effects on increasing population, especially if highway system was also available in that region. They also argued that most of the regions without the Shinkansen line nor highway

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[92] Ibid. 2
[93] Ibid. 42
[94] Ibid. 6

network has experienced decrease of population. Qualitatively, they argued that there are three types of regions that HSR will have different impacts; Region A like Tokyo metropolitan area, Region B like Sendai city, the center of Tohoku region, and the Region C like Furukawa, a small size city with Shinkansen stops. They discussed impacts of HSR on these regions respectively.

For the largest region A (like Tokyo): This type of region refers to a megalopolis like Tokyo. "Export" of highly specialized person-related service by firms to smaller regions will increase with less travel cost. Economic development will occur in the region, but the magnitude is relatively small when compared with the existing large size of economic activities and hard to be measured.

For the mid-size region B (like Sendai): This type of region has been a political, economic and, cultural center of broader area including the region C. Although some business will be lost to larger organizations from the region A, new service will develop in the region B with less cost by using new knowledge and information obtained from the large region A. Also consumption in the region B will increase for the "imported service" from other regions with less cost. In total, considerable economic development will be expected in this type of region.

For the small-size region C (like Furukawa): This type of region refers to a local city and its surrounding area. It often does not have enough business accumulation to get opportunity for cheaper resource and its production size will not change significantly. However, consumption inside will increase for "import effect" as in the large regions. In total, limited development will be expected.

In summary, they expressed a concern that a HSR may accelerate further concentration into larger cities, which is not a good scenario for the C-type small regions.

3.3.2 Europe

Compared to the Japanese Shinkansen system, the European HSR has shorter history and it is harder to evaluate impacts of HSR on its regions. Vickerman[95](1997) pointed out that the European integrated HSR network is on too early stage to estimate its impact on regions. He summarized the status-quo of European HSR, including French TGV, German ICE, Italian Direttissima,

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[95] Ibid. 4

and Spanish AVE. He pointed out that high speed rail developments in Europe have occurred for many reasons, but without any clear overall plan to form an entire network.

Sand[96](1993) reviewed the impacts of French TGV and found that Lyon Part-Dieu have experienced significant economic development.

> *The area around the TGV station (at Lyon Part-Dieu) is now the most sought -after location for office space in Lyon: new commercial quarter around the new station experienced total office space rose by 43 per cent between 1983 and 1990. There are four factors responsible for the strong growth: easy access to and from the station by foot; convenience for customer; a steady flow of businessmen through the district; and high visibility of the firms from the TGV trains... (However,) the impact of TGV is limited to a relatively small area of Lyon near the station, and it is limited thereof mainly to advanced service firms that require good access to Paris.*

He argued that the TGV has affected the behavior and location decisions of businesses and has had noticeable development effects around some stations. However, he also points out that access to the TGV was just one of a number of factors cited when making business relocation decisions. Other factors included the overall economic situation; the entire transportation network (road and rail); and public sector assistance.

Cervero and Bernick[97](1996) investigated the impacts of the TGV lines on French cities and found that two stations en route, Lille and Lyon Part-Dieu, have enjoyed development in several aspects after the TGV debut. However, they also noted that TGV access alone has not been sufficient to generate station-area growth and good conditions in terms of strong regional economy and active public sector participation in land use planning have existed in their background. TGV may be necessity for development; but is not sufficient itself. They also pointed out the fact that the TGV has failed to spawn new town development, and it would cast a doubt on effectiveness of high-speed rail to produce economic growth.

In terms of cost-benefit analysis for integrated European high-speed rail network, Allport and Brown[98](1993) estimated the aggregated benefits of the entire project. They made traditional cost-benefit analysis that showed the feasibility of the project, but they also tried to include

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[96] Ibid. 2

[97] Ibid. 42

[98] Allport, Roger J, Brown, Mark B.(1993), "Economic Benefits of the European High Speed Rail Network", Transportation Research Record No.1381, pp.1-11

additional benefits such as in-travel work capability and new opportunities for one-day return trips.

3.3.3 U.S.

Although high-speed rail system in the U.S. is not well developed, the feasibility studies of HSR for several corridors have been performed. Here we discuss the most recent analysis made by the Federal Railroad Administration of the U.S. Department of Transportation in 1997: FRA[99](1997) of USDOT published a report of cost-benefit analysis of HSR on several corridors in the U.S. Their analysis included California North-South between Bay Area to San Diego, Chicago Hub Network between St. Louis to Detroit through Chicago, Florida between Tampa and Miami, the Northeast Corridor, Pacific Northwest between Vancouver to Portland, and Texas Triangle between Dallas/Fort Worth, Houston and San Antonio. They performed extensive cost-benefit analysis for each corridor with several case of different operating speed from 90 mph to Maglev.

Table 3-1: Net-benefit of HSR projects with respect to corridors and technologies of speed [100]♦

Maximum Speed	90 mph	110 mph	125(F*) mph	125(E) mph	150(F) mph	150(E) mph	New HSR	Maglev
California North-South	$3,228	$4,247	$93	$191	$1,383	$1,889	$3,670	$3,422
Chicago Hub	$3,194	$4,023	$3,280	$2,118	$2,466	$997	($3,984)	($5,951)
Florida	$195	$402	$335	($173)	N/A	N/A	$210	($1,402)
Northeast Corridor	N/A	N/A	N/A	N/A	N/A	N/A	$648	$2,128
Pacific Northwest	$1,447	$1,434	$1,168	$333	N/A	N/A	($4,622)	($10,028)
Texas Triangle	$749	$1,122	($441)	($1,318)	($520)	($2,015)	$570	($2,302)

Their results show that incremental HSR is feasible on most of the corridors, but the best technology option varies among corridors. For some corridors, it is better to build a new HSR instead of upgrading existing right-of-way. The Texas Triangle is one of them; it says new HSR will make profits while incremental HSR at the speed of 125 mph or more will not. The reasons

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[99] FRA, USDOT(1997), "High-Speed Ground Transportation for America", published in Sept.

[100] Ibid. 99

♦ Dollar amounts are present values in millions for the period 2000-2040 are that travelers are very time sensitive and the higher speed will attract more passengers from air, while improving existing right-of-way becomes very expensive to allow higher speed.

As for case studies of existing rail systems, three studies were found for normal transit systems. Firstly, DOT[101](1979) conducted study of the economic and financial impacts of the Bay Area Rapid Transit (BART), concluding that this rapid transit system had no significant effect on regional economic growth.

More than 15 years later, Cervero and Landis[102](1996) analyzed the impact of the BART system on land use and development impacts. They investigated the changes in the area for the 20 years since the BART started operation in 1973 suggesting there might be enough time to internalize the benefits of the BART in the area. They found some concentration have occurred at the downtown area along the line, but the magnitude is limited.

> *While BART appears to have helped bring about a more multi-centered regional settlement pattern, such as inducing mid-rise office development near the Walnut Creek and Concord stations, it has done little to stem the tide of freeway-oriented suburban employment growth over the past two decades. Indeed, recent office additions near East Bay stations pale in comparison to the amount of floorspace built in non-BART freeway corridors.*

Another DOT research project on SEPTA[103](1991), conducted by the Urban Institute and Cambridge Systematics, Inc.(1991), argued that shutting down metropolitan Philadelphia's transit system would have a very substantial negative effect on business sales, personal income, employment, and population within the region. Huang(1994)[104] summarized these two studies by methodological differences.

> *The 1979 BART impact study attempts to isolate the effects of transit through key informant interviews and shift-share analysis. Regional growth, however, is a complex process involving many related factors, so it is difficult to identify the effect of any single variables. Moreover, theory suggests that transit's effects on firm costs are, at best, indirect. The 1991 SEPTA study, in contrast, focuses on the directly measurable effects of transit - decreases in travel time and congestion - and it uses a model that necessarily*

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[*] 'F' denotes for non-electrified; 'E' denotes for electrified HSR.

[101] Grefe, Richard, and Angus N. McDonald. 1979. *The Economic and Financial Impacts of BART: Final Report.* Springfield, VA: NTIS(Apr.)

[102] Cervero, Robert, Landis, John(1997), "Twenty Years of the Bay Area Rapid Transit System: Land Use and Development Impacts", Transportation Research Part A: Policy and Practice: Vol.31A, No.4

[103] The Urban Institute and Cambridge Systematics, Inc. 1991. *The Economic Impacts of SEPTA on the Regional and State Economy: Final Report.* Washington, D.C.: U.S. Department of Transportation

[104] Ibid. 77

> *translates those effects into increased economic growth. So long as transit provides any travel-related benefits, the study's design virtually ensures that some positive effect on economic growth will be found.*

3.4 Other Theories and Indicators to Capture Impacts of HSR

(1) Proposal for another indicator to represent accessibility

Travel time reduction due to infrastructure development will increase the accessibility of the regions connected by the HSR. However, accessibility of a region is affected not only by travel time but several other aspects such as frequency of service and reliability of the transportation mode. Nakagawa and Kato[105](1990) proposed "maximum stay time" as an indicator that can be used instead of travel time in accessibility analysis. They argued, when frequency of a mode is quite small in inter-city transportation or the reliability of operation is not high, a traveler is in effect paying additional time costs. To reflect these aspects, they defined "maximum stay time" as the length of time between the time a traveler arrives at he/her destination and the time he/she has to depart there to make one-day return trip. He/she has to start trip after 6AM at the origin, and has to come back the origin before the midnight of same day. The maximum stay time is then subject not only to travel time, but also frequency and timetable. They argued this indicator is more appropriate for inter-city accessibility.

Nakagawa et al. (1994[106]) developed this maximum stay time to inclusive accessibility in quantitative forms. They calculated accessibility from maximum stay time and population for every prefecture in Japan and showed the impacts of empirical transportation infrastructure investment on accessibility. However, these two studies did not do a cost-benefit analysis (CBA) to estimate the feasibility of specific projects. However, in a sense, it can be said that these studies considered accessibility as a benefit of HSR.

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[105] Nakagawa, Dai and Kato, Yoshihiko(1990),"Travel Time and Maximum Stay Time: Spatial Resistance of Inter City Access", *Kousokudoro to Jidosha*:33, 12 (in Japanese)

[106] Nakagawa et al.(1994), "A Study on the Changes of Possibility of Mutual Access by Improvement of Inter City Transportation", *Doboku Gakkai Ronbunshu*: No.482/IV-22 (In Japanese)

(2) One-day return trip

Plassard[107](1994) distinguished HSR from mere speed up of existing trains due to the psychological impacts and made an observation about threshold of travel time.

> *In the analysis of high speed, it is not enough to consider the concept of speed alone, which is a technical exploit, nor even that of transport time. Insofar as human activity is still subject to a daily cycle, two thresholds are of particular importance: that of the day, and possibly, that of the half-day. Representations of space are not all the same when users can make the return journey over certain links in the same day. The introduction of the TGV service between Lyons and Paris has clearly demonstrated this, since the behavior of frequent users over this link seems to be much closer to that of regular users of the Paris regional express network than that of normal main-line train passengers.*

Allport and Brown[108](1993) also argued that the benefits are not linear with respect to travel time saving: there is a threshold for business travelers that allows them to make one day return trip. According to them, the threshold time is 4.5 hours for door to door basis and therefore 3 hours in train or 1 hour on airplane. Also in-vehicle work capability as compared with other modes during a trip is considered as a benefit of the HSR.

(3) Others

Kobayashi and Okumura[109](1997) proposed a dynamic multi-regional growth model with the scale effect of knowledge. They regard knowledge as non-rival, partially exclusive goods and railway systems as providing production sectors of different cities with the opportunity for face-to-face communication for knowledge production. Their hypothetical model shows that HSR will decrease the cost of the communication and lead to regional growth. Their model implies that a city that initially accumulated knowledge becomes more advantaged by HSR, and initial profiles of population and capital stock are less important for future growth.

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[107] Plassard, F. 1992. European Conference of Ministers of Transport, "Report of the Ninety-Fourth Round Table on Transport Economics: Regional Policy, Transport Networks and Communications", held in Paris on 5th-6th; November

[108] Ibid. 98

[109] Kobayashi, Kiyoshi and Okumura, Makoto(1997), "The growth of city systems with high-speed railway systems", *Annals of Regional Science*:31

Blum et al.[110] (1997) pointed out that HSR can solve two different accessibility problems: one is a potential substitute for air traveling, and the other is linking together many cities and hence creating a new type of region or corridor with a high intra-regional accessibility. They focused on the secondary benefits in all short-run, medium-run, and long-run.

3.5 Findings and Conclusion

Through this literature review, we found that a high-speed rail investment will have positive impacts on regional economy to some extent when we view it as public infrastructure investment, but its magnitude is not guaranteed to be as high as other public investments. Transportation infrastructure might be a necessity for regional development, but it is not sufficient alone. However, if a careful and inclusive net-cost analysis is positive for a specific HSR project, it would be safe to say the project is feasible and may have positive impact as a whole. So evaluation should be on the basis of each case; general conclusions are hard to derive. The problem arises when the cost-benefit analysis fails to prove feasibility of a project.

It is also noted that there are HSR benefits that exist but are hard to be represented quantitatively. For example, the possibility of making one-day return trip, eliminating transfer of trains, and reduction in psychological distance by brand-new HSR can be an example of such benefit.

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[110] Blum, U, Haynes, K.E., Karlsson, C.(1997), "The regional and urban effects of high-speed trains", *Annals of Regional Science*:31

4. Methods to Estimate Benefits of High-speed Rail

4.1 Introduction

In this chapter, we will discuss methods to estimate the benefits to regions of high-speed rail. However, performing an extensive CBA discussed in the previous chapter is beyond the scope of this thesis. Rather, we will focus on the change of travel time by several HSR projects and see how different technologies of HSR will have impacts on travel time. The underlying idea is that the time saving gained by higher speed operation is the major benefit of high-speed rail, as Shearin[111](1997) argued in his study, already quoted in Chapter 3. The impacts on travel time by several HSR projects are analyzed theoretically and quantitatively. Several hypothetical regions will be introduced to illustrate the travel time saving under various scenarios.

4.2 Models for Travel Time Savings

As discussed in the previous chapters, travel time is one of the most important level-of-service variables for transportation modes. Consequently, travel time and fare level directly affect the ridership. While fare level is relatively easy to modify, travel time is very hard to change because it is related to several issues including technologies and in many cases, the operational speed is decided before other characteristics. It is noted that raising maximum speed is generally expensive, but its impact on travel time is not always clear. Here we create analytical models to understand how travel time is influenced by technology improvement and operational strategies of high-speed rail.

4.2.1 Model 1

Following is the simplest model of train operation. Using this model, we will analyze the change of travel time in several cases. We use this basic model to see the basic impacts of several changes such as improvement of rolling stock or right-of-way.

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[111] Ibid. 87 (refer to the page 57 of this thesis)

assumption

- Trains run between Station 1 and 2 as fast as possible using the maximum capability in terms of maximum speed and acceleration / deceleration rate.
- Terrain is flat and there is no gradient between two stations so that maximum speed and acceleration/deceleration rate are always constant.

notation

L: distance between station 1 and 2
t: required travel time between 2 stations
V: average speed between 2 stations
V_0: maximum speed (constant)
a: acceleration rate (constant)
b: deceleration rate (constant)

The travel time t is a function represented as follows:

$$t = \frac{L}{V} = f(L, V_0, a, b)$$

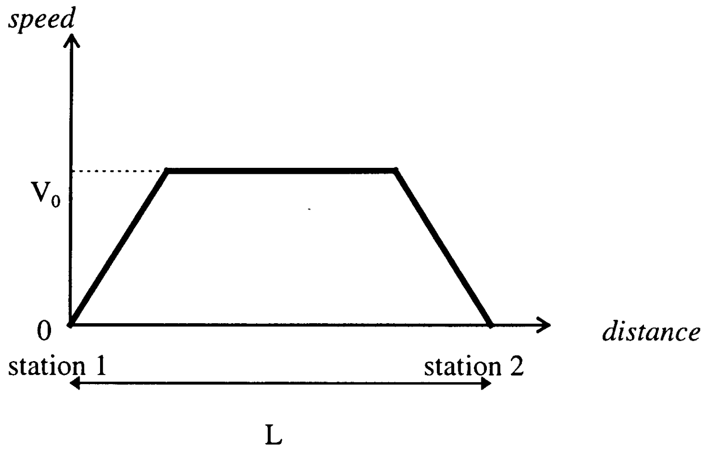
4.2.1.1 Base Case

If we assume the following:

- The distance between two stations is long enough for a train to reach its maximum speed and continue to run at the speed for certain time.
- There is no partial speed limit due to tight curves.

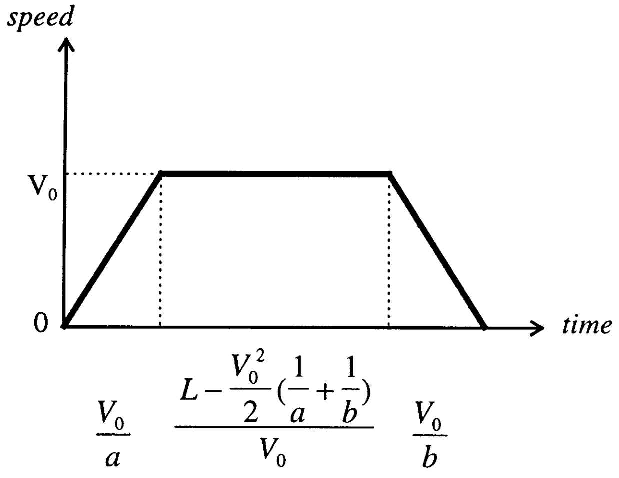
The relationship between speed and distance of a train running between the station 1 and 2 is represented as follows:

[speed-distance]



Then the relationship between train's speed and travel time is as follows.

[speed-time]



(Note that the area of shaded trapezoid is equal to the trip length L.)

The required travel time t in this case is:

$$\therefore t=\frac{V_0}{a}+\frac{L-\frac{V_0^2}{2}(\frac{1}{a}+\frac{1}{b})}{V_0}+\frac{V_0}{b}$$

Then the average speed V between Station 1 and 2 is

$$\therefore V = \frac{L}{t} = \frac{L}{\frac{V_0}{a} + \frac{L - \frac{V_0^2}{2}(\frac{1}{a} + \frac{1}{b})}{V_0} + \frac{V_0}{b}}$$

Next, we consider following 5 cases to analyze how improvement or restriction has impacts on the travel time and thus average speed.

- Recommended minimum distance between stations
- Increase maximum speed
- Increase acceleration / deceleration rate
- Impact of setting partial speed limit
- Impact of building a new station

4.2.1.2 Recommended distance between stations

4.2.1.2.1 *Formulation*

In the base case, we assumed that the distance between two stations is long enough for a train to reach its maximum speed. However, if the distance between stops is not long enough, a train may not reach its maximum speed. This is not efficient and should be avoided because that train can not take advantage of its high speed. In such case, the average speed V^* between two stations is:

$$V^* = \frac{L}{\sqrt{\frac{2bL}{a(a+b)}} + \sqrt{\frac{2aL}{b(a+b)}}} \qquad \forall V_0 \geq \sqrt{\frac{2abL}{a+b}}$$

Note that the average speed in this case is not a function of maximum speed V, but of acceleration and deceleration rate, and distance. Thus further improvement of maximum operating speed becomes meaningless in this case.

It is clear that a short distance between stations such that a train cannot reach its maximum speed is not useful for increasing average speed and thus decreasing travel time; keeping a minimum distance between stations is recommended. Such minimum distance L* is

$$L^* \geq \frac{V_0^2 (a+b)}{2ab}$$

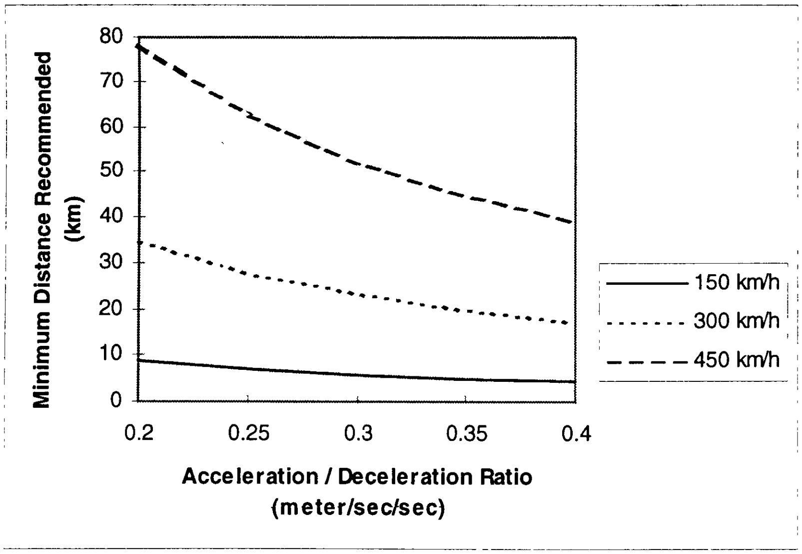
4.2.1.2.2 *Analysis*

We computed the value of L^* with several combinations of maximum speed and acceleration / deceleration rate. We assume that the acceleration rate and deceleration rate are identical for all of the following analyses. The result is summarized in the following table and figure.

Table 4-1: The Distance Required to Reach Maximum Speed (Kilometer)

Acceleration and Deceleration rate (meter/sec/sec)	Maximum Speed 150 km/h	Maximum Speed 300 km/h	Maximum Speed 450 km/h
0.2	8.68	34.72	78.13
0.25	6.94	27.78	62.50
0.3	5.79	23.15	52.08
0.35	4.96	19.84	44.64
0.4	4.34	17.36	39.06

Figure 4-1: The Distance Required to Reach Maximum Speed



4.2.1.2.3 *Findings*

- Needless to say, the more a train's maximum speed is, the longer distance required to utilize the potential of the train if acceleration / deceleration rate is constant.
- The impact of acceleration / deceleration rate becomes significant as the maximum speed becomes higher: in other words, to reduce the distance to reach maximum speed, acceleration / deceleration rate as well as maximum speed should be improved.

Next, we see how an increase in maximum speed will affect the travel time and average speed.

4.2.1.3 Increase maximum speed

Increasing maximum speed will reduce the travel time between stations. Here we show the impact of increased maximum speed on travel time. Note that increased maximum speed also increase the necessary time reach the maximum speed if acceleration / deceleration rate is constant, but here, we assume the distance between stations is enough for a train to reach its maximum speed.

4.2.1.3.1 *Formulation*

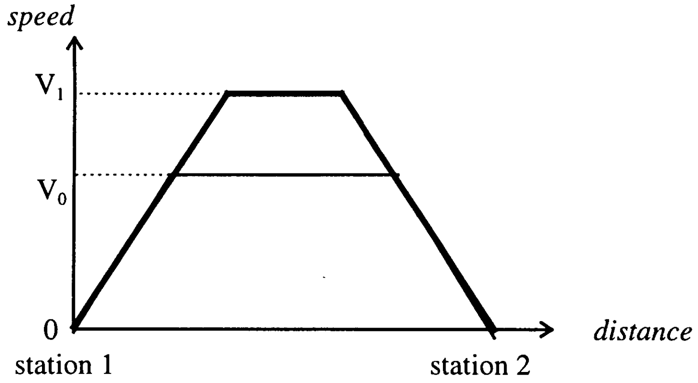
notation

V_1 : improved maximum speed

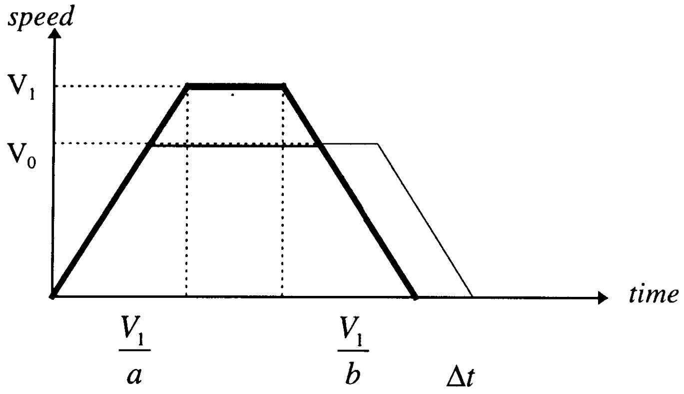
Bold line: represents the movement of a train with higher maximum speed

Narrow line: represents the movement of old train

[speed-distance]



[speed-time]



As long as the trip distance L is constant, the area of new trapezoid is equal to that of old trapezoid and the area of shaded trapezoid and that of parallelogram are also same.

So, $$\frac{(V_1-V_0)}{2}((\frac{2L}{V_1}-\frac{V_1}{a}-\frac{V_1}{b})+\frac{V_1-V_0}{a}+\frac{V_1-V_0}{b})=V_0\Delta t$$

and solving this equation for Δt leads

$$\Delta t = \left(\frac{L}{V_0 V_1} - \frac{1}{2a} - \frac{1}{2b}\right)(V_1 - V_0)$$

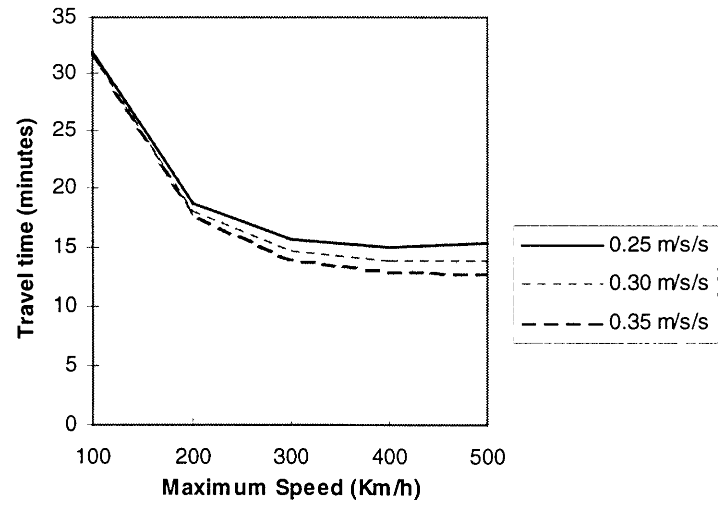
4.2.1.3.2 *Analysis*

We analyze how the difference in maximum speed influences the travel time between two stations. Here, the distance between two stations is set to 50 km. The result is shown in the following Table 4-2 and Figure 4-2 with three different assumptions in acceleration / deceleration rate.

Table 4-2: Impacts of Maximum Speed on Travel Time (minutes)

Maximum Speed (km/h)	Acceleration Deceleration Rate 0.25 m/s/s	Acceleration Deceleration Rate 0.3 m/s/s	Acceleration Deceleration Rate 0.35 m/s/s
100	32	32	31
200	19	18	18
300	16	15	14
400	15	14	13
500	15	14	13

Figure 4-2: Impacts of Maximum Speed on Travel Time



4.2.1.3.3 *Findings*

- While keeping acceleration / deceleration rate constant, we found the decrease in travel time will diminish as the maximum speed goes beyond 300 km/h. This is mainly because of the assumption of distance between stations (50 km) and acceleration / deceleration rate.
- The difference in acceleration / deceleration rate has limited impacts on travel time, compared to the maximum speed.

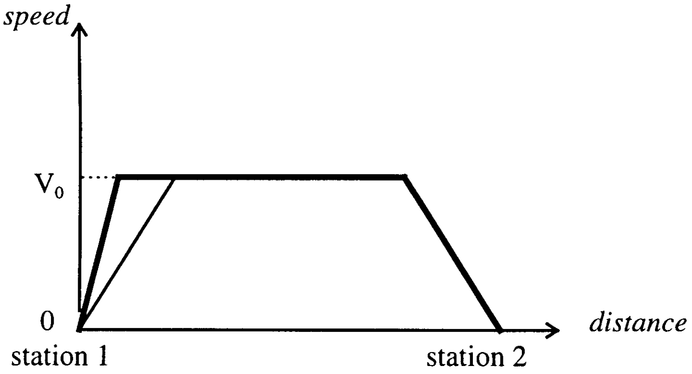
4.2.1.4 Increase acceleration / deceleration rate

Increased acceleration / deceleration rate will reduce necessary time to reach maximum speed and consequently travel time. The impact of deceleration is identical to of acceleration in terms of travel time. Unlike the maximum speed, there would be a human comfort limit in increasing acceleration / deceleration rate, because normally HSR passengers are not required to fasten a seat belt, and very high acceleration or deceleration rate will cause discomfort for them. However, emergency braking is an exception, because priority changes to avoid an accident at that time.

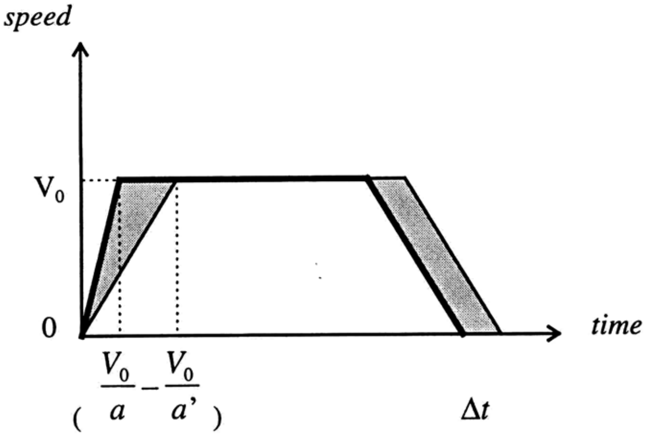
4.2.1.4.1 *Formulation*

notation a' : improved acceleration rate

[speed-distance]



[speed-time]



Note that the area of trapezoid made by time-axis and narrow lines represents the sum of distance old train ran while one made by time-axis and bold lines represents the distance that newer train runs.

As long as the distance L between two stations is constant, the area of new trapezoid is equal to the area of old trapezoid. Therefore the area of shaded triangle and that of parallelogram are also equal.

So,

$$\frac{V_0}{2}(\frac{V_0}{a} - \frac{V_0}{a'}) = V_0 \Delta t$$

and solving this equation for Δt leads

$$\Delta t = \frac{V_0}{2}(\frac{1}{a} - \frac{1}{a'})$$

Note that this is also applicable when we improve deceleration rate instead of acceleration rate. When deceleration rate b improve to b', Δt is

$$\Delta t = \frac{V_0}{2}(\frac{1}{b} - \frac{1}{b'})$$

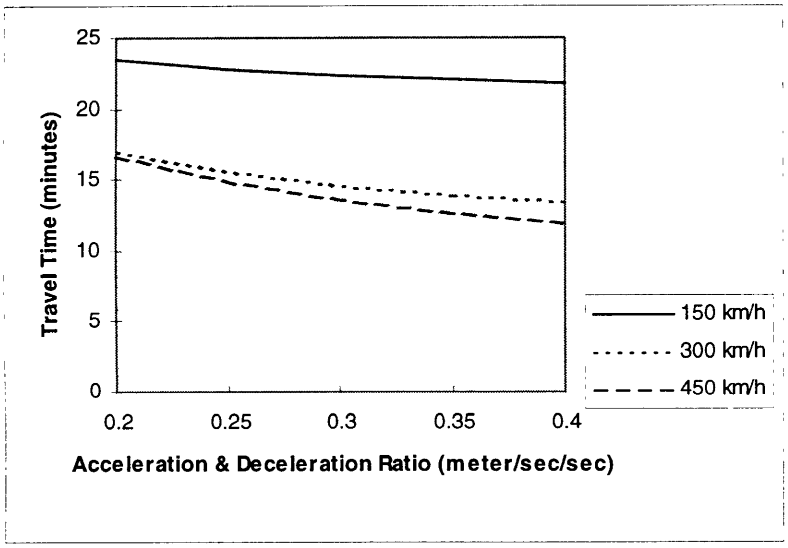
4.2.1.4.2 *Analysis*

We analyze how the difference in acceleration / deceleration rate influences the travel time between two stations. Here, the distance between two stations is also set to 50 km. The result is shown in the following graph with three different magnitudes for maximum speed.

Table 4-3: Impact of Acceleration / Deceleration Rate on Travel Time (minutes)

acceleration and deceleration rate (meter/sec/sec)	Maximum Speed 150 km/h	Maximum Speed 300 km/h	Maximum Speed 450 km/h
0.2	23	17	17
0.25	23	16	15
0.3	22	15	14
0.35	22	14	13
0.4	22	13	12

Figure 4-3: Impact of Acceleration / Deceleration Rate on Travel Time



4.2.1.4.3 *Findings*

- At the given condition, the acceleration / deceleration rate has limited impact on travel time and the difference in maximum speed has more impacts on travel time.
- The distance between stations (50 km) would be the reason why the difference in travel time between 300 km/h case and 450 km/h case is smaller than between 150 km/h case and 300

km/h case. This relatively shorter distance between two stations would not be long enough to take the advantage of 450 km/h operation.

4.2.1.5 Recommended Station Distance for Technologies

Using previous analyses, we here estimate how the distance between stations might affect average speed (thus travel time) with various assumptions of maximum speed. Three cases are analyzed with the maximum speed of 150, 300, 450 km/h. We will study the relationship between distance between stations and average speed.

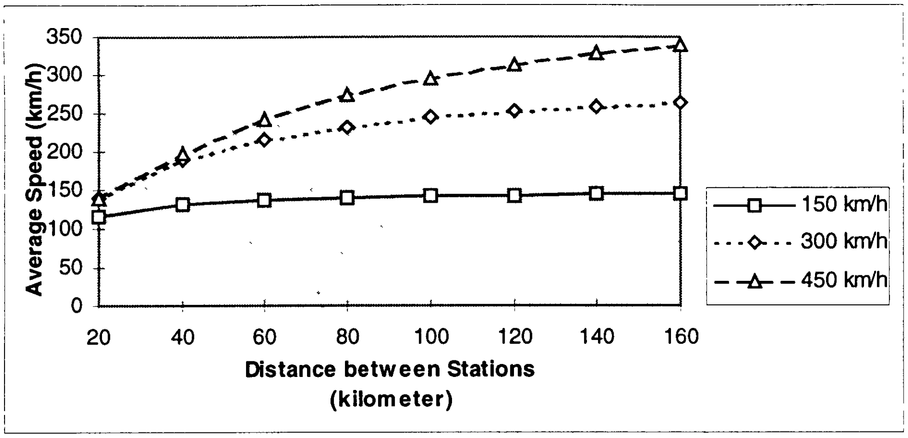
4.2.1.5.1 *Analysis*

We analyzed how the difference in distance between two stations influences the travel time and average speed between two stations. The acceleration / deceleration rate is set to 0.3 (meter/second/second). The result is shown in the following Figure 4-4 with three different assumptions in the maximum speed.

Table 4-4: Impact of distance on average speed

Distance between Stations (kilometer)	Maximum Speed 150 km/h	Maximum Speed 300 km/h	Maximum Speed 450 km/h
20	116	139	139
40	131	190	197
60	137	216	241
80	140	233	273
100	142	244	296
120	143	251	314
140	144	257	328
160	145	262	339

Figure 4-4: Impact of Distance on Average Speed



4.2.1.5.2 *Findings*

- Generally the longer distance a train runs, the more average speed it gains, because the length the train can run at the maximum speed increases. However, if a train operates on the maximum speed of 150 km/h, the increase of average speed will diminish when the distance is more than 60 km. From Figure 4-4, a 40 km seems reasonable distance between two stations for the 150 km/h operation.
- On the other hand, when the maximum speed is 300 or 450 km/h, the average speed will continue to increase at higher rate. From Figure 4-4, a distance of more than 80 km should be kept for the 300 km/h and 450 km/h operation to utilize high maximum speed.

We have found the respective station distance for three cases with different maximum speed. Next, we will analyze the impact of setting partial speed limit or adding a new station en route.

4.2.1.6 Setting partial speed limit

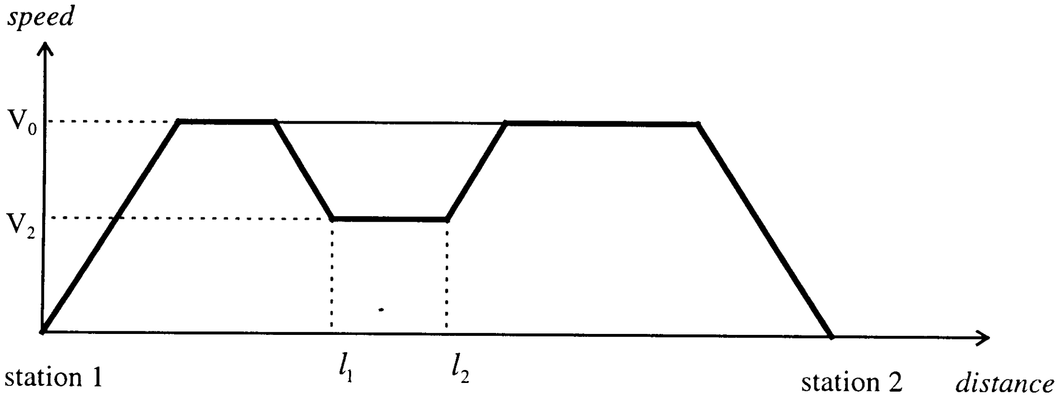
Sometimes it is necessary to set a partial speed limit on tight curves to avoid derailment of trains. However, it increases the travel time and we analyze its impact on travel time.

4.2.1.6.1 *Formulation*

notation

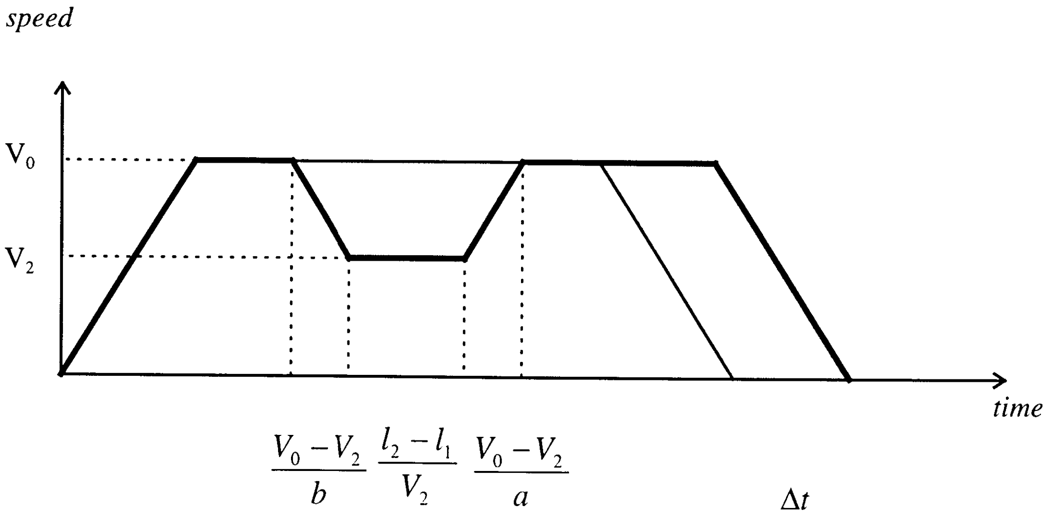
V_2 : the partially limited speed
l_1 : the location where lower speed limit is applied
l_2 : the location where the speed limit is over

[speed-distance]



When partial speed limit is applied, total trip time will increase.

[speed-time]



Since the area of shaded trapezoid and parallelogram is equal, making equation and solving it for Δt leads:

$$\Delta t = \frac{(V_0 - V_2)(l_2 - l_1)}{V_0 V_2} + \frac{(a+b)(V_0 - V_2)^2}{2ab}$$

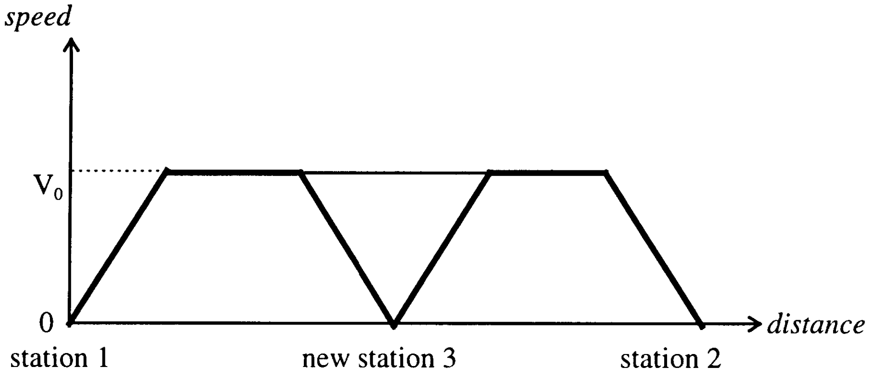
This Δt represents additional trip time when speed limit is applied. This also can be the reduction of trip time when present speed limit be removed.

4.2.1.7 Building a new station

If a new station is built midway between station 1 and station 2, it will affect total travel time.

4.2.1.7.1 *Formulation*

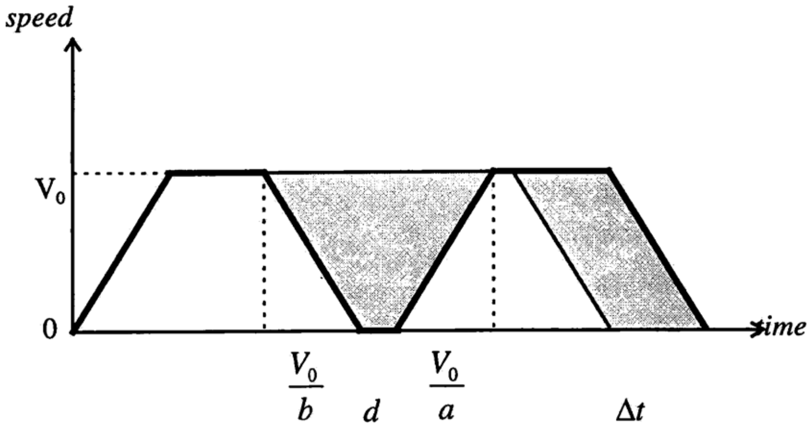
[speed-distance]



notation

d: dwell time at new station 3

[speed-time]



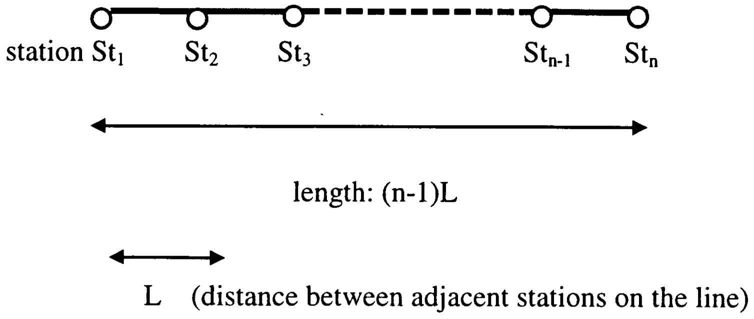
$$\frac{\frac{V_0}{b} + 2d + \frac{V_0}{a}}{2} = \Delta t$$

Solving for Δt leads

$$\Delta t = d + \frac{V_0(a+b)}{2ab}$$

The increase in travel time consists of dwell time at the station and time required to decelerate from the maximum speed and accelerate from halt. Next,, we study a case with multiple stations.

4.2.1.8 Multiple Stations



When the distance between adjacent stations is long enough for a train to reach its maximum speed and unit travel time between adjacent stations is t*, travel time t between Station l and Station m (l<m) is:

$$t = (m - l)t^* + (m - l - 1)d$$

If a traveler has to make a transfer between high-speed rail and local train at the station n (l<n<m) and the unit travel time for high-speed and local train is t_1 and t_2 respectively, the travel time t^{**} is then:

$$t^{**} = (n - l)t_1 + (n - l - 1)d + (m - n)t_2 + (m - n - 1)d + transfer$$

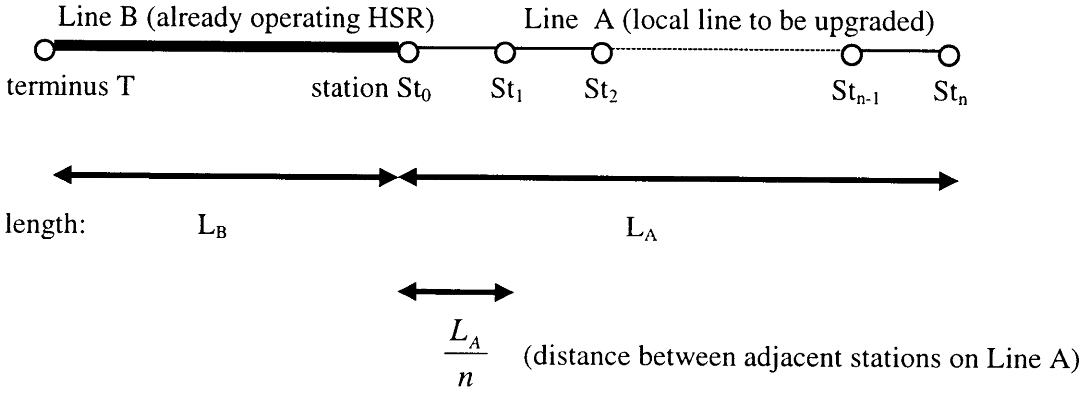
4.2.1.9 Summary

In this section, we have analyzed basic relationship between travel time and geographical and operational features. We proposed an analytical model to evaluate the impacts on travel time in two-station case and multiple station case. We also derived recommended distance between two stations under some assumptions. Using these results, a more realistic model is created in the following section.

4.2.2 Model 2

This Model 2 extends Model 1 to a more practical level. It models two hypothetical lines connected to each other at one end. "Line A" is a local line with (n+1) stations, while "Line B" is an existing HSR which is connected to the Line A at station St_0. At present, there is no compatibility between two lines and all passengers using both lines have to change trains at the station St_0. We suppose that now the line A is to be upgraded for higher level of service.

Image:



Assumption and notation

1. The HSR line B has station St_0 and terminus T.
2. There are (n+1) stations on the local line A. (St_0, St_1, St_2,,, St_n)
3. All passengers make return trip on the same transportation mode.
4. The length of lines A and B are L_A and L_B respectively.
5. Both route A and B are flat and have no inclination. (so acceleration/deceleration are identical in both directions.)
6. Each station on the line A is at the same distance to its adjacent station, so for all station on line A, distance to the adjacent station is L_A / n.
7. Average speed on line A and B is s_A and s_B respectively. Note that these are average speed, not the maximum speed. The reason why we use average speed is to avoid very complicated expressions in the Model 2. We note that average speed is a function of maximum speed and maximum speed of train is more used as a representing index of HSR service, because it represents the level of technologies implemented and is directly associated with construction cost. We will use maximum speed again in the scenario analysis of hypothetical regions.

8. Frequency of train on line A and B is F_A and F_B, so as to headway of line A and B is $1/F_A$ and $1/F_B$ respectively.
9. Passengers already know the timetable before coming to station so that waiting time to board first train of his/her trip can be neglected.
10. No expressing and bypassing are considered. In other words, every train stops all the stations.

Firstly, analysis of travel time at status quo is given, then four options are considered. These four options include:

- **"Incremental" high-speed rail**

  The speed-up effect has impact only on the Line A and no compatibility is given between Line A and Line B so that physical transfer must be made by the passengers using both of the Line A and B.
- **"Mini" Shinkansen**

  The magnitude of speed-up is same as incremental HSR. However, now the trains running on Line A can directly run through the Station St_0 onto Line B. The transfer time at the St_0 is eliminated.
- **Conventional Shinkansen**

  The Line A is improved to the same quality of Line B. The speed on the Line A is further improved to that of the Line B while other conditions hold with above case.
- **Maglev**

  Totally different dedicated rights-of-way train system is introduced. However, the analytical difference between above case is only the difference of speed on Line A and B.

According to above assumptions, impacts on travel time for each case is examined.

4.2.2.1 Status quo

For the line B, travel time between station St_0 and terminal T is:

$$t_{T0} = \frac{L_B}{s_B}$$

For each adjacent pair of stations on the line A, travel time between them is supposed to be identical. Then the unit travel time t^* between station St_a and $St_{(a+1)}$ is:

$$t_0^* = \frac{L_A}{n \times s_A}$$

For users within Line A

For passengers from station St_l to St_m ($0 \leq l < m \leq n$), total travel time for return trip is:

$$t_0 = \frac{2(m-l)L_A}{ns_A}$$

For passengers using both line A and B

It is likely that some effort has already made for better connection at station St_0 between line A and B. However, there would.exist other restrictions (e.g. clockwise timetable or station platform capacity for trains) while making timetable and the waiting time cannot be always minimized. We assume the waiting time t_w for passengers connecting line A and B at station St_0 as follows:

minimum: 0
maximum: $1/F_A$ or $1/F_B$
average: $1/4F_A$ or $1/4F_B$

Using above value, the travel time for passengers going from terminal T to station St_m on route A is:

$$\begin{aligned} t_{Tm} &= t_{T0} + m \times t_A + t_w \\ &= \frac{L_B}{s_B} + \frac{mL_A}{ns_A} + \frac{1}{4F_B} \end{aligned}$$

For passengers from station St_m on route A to terminal T, it is:

$$\begin{aligned} t_{mT} &= t_{T0} + m \times t_A + t_w \\ &= \frac{L_B}{s_B} + \frac{mL_A}{ns_A} + \frac{1}{4F_A} \end{aligned}$$

As a result, the total return travel time for them is:

$$t_0 = t_{\mathrm{Tm}} + t_{\mathrm{mT}} = \frac{2L_B}{s_B} + \frac{2mL_A}{ns_A} + \frac{1}{4F_A} + \frac{1}{4F_B}$$

4.2.2.2 Case 1: Incremental high-speed rail

Line A is upgraded to allow trains higher speed, but no physical connection is made between the line A and B.

Speed up effect

Firstly, the average speed on route A will be improved. When the average speed increases by rate of c_1, new unit travel time on route A is:

$$t_1^* = \frac{L_A}{n \times c_1 s_A}$$

Passengers within Line A

For passengers from station St_l to St_m ($0 \le l < m \le n$), total travel time for return trip is:

$$t_1 = \frac{2(m-l)L_A}{nc_1 s_A}$$

Change of travel time by the project is:

$$\Delta t_1 = \frac{2(m-l)L_A}{nc_1 s_A} - \frac{2(m-l)L_A}{ns_A}$$
$$= \frac{2(1-c_1)(m-l)L_A}{nc_1 s_A}$$

For passengers using both line A and B

If frequency of trains on line A is not changed, waiting time at station St_0 does not change and only increased speed contributes to travel time reduction.

So total travel time for passengers going from terminal T to station St_m on route A is:

$$\mathrm{t}^{1}_{\mathrm{Tm}} = t_{T0} + m \times t_1^* + t_w$$
$$= \frac{L_B}{s_B} + \frac{mL_A}{nc_1 s_A} + \frac{1}{4F_B}$$

and for passengers from station $\mathrm{St_m}$ on route A to terminal T:

$$\mathrm{t}^{1}_{\mathrm{mT}} = t_{T0} + m \times t_1^* + t_w$$
$$= \frac{L_B}{s_B} + \frac{mL_A}{nc_1 s_A} + \frac{1}{4F_A}$$

As a result, the total return travel time for passenger using the Line A and B is:

$$t_1 = t_{\mathrm{Tm}} + t_{\mathrm{mT}} = \frac{2L_B}{s_B} + \frac{2mL_A}{nc_1 s_A} + \frac{1}{4F_A} + \frac{1}{4F_B}$$

Change of travel time by the project for them is:

$$\Delta t_1 = t_1 - t_0 = \frac{2(1-c_1)mL_A}{nc_1 s_A}$$

Time Savings

Within Line A

Since change of travel time for one passenger is Δt_1,

accumulative time-saving for all passengers within line A is

$$-\sum_{t=0}^{n-1} R_{t(t+1)} \frac{2(1-c_1)L_A}{nc_1 s_A}$$

There is no time reduction with respect to travel time of line B and transfer time, and the total time saving TS_1 by the Case 1 is also:

$$TS_1 = -\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_1)L_A}{nc_1 s_A}$$

4.2.2.3 Case 2: Mini-Shinkansen

The Line A is upgrraded to allow the same speed with plan 1, but now trains operating on the Line A can directly run through the existing Shinkansen Line B so that no transfer is necessary.

speed up effect

The average speed on route A will be improved. When the average speed increases by rate c_2, new unit travel time on route A is:

$$t_2^* = \frac{L_A}{n \times c_2 s_A}$$

Within Line A

For passengers from station St_l to St_m ($0 \le l < m \le n$), total travel time for return trip is:

$$t_2 = \frac{2(m-l)L_A}{nc_2 s_A}$$

Change of travel time by the project is:

$$\Delta t_2 = \frac{2(m-l)L_A}{nc_2 s_A} - \frac{2(m-l)L_A}{ns_A}$$
$$= \frac{2(1-c_2)(m-l)L_A}{nc_2 s_A}$$

For passengers using both line A and B

Since mini-Shinkansen can run both on line A and B, the transfer time at station St_0 is not required. However, some time will be necessary for operator to adjust equipment to different route characteristics[•], and it is natural to set a fixed length of time required at station St_0 [••]

So total travel time for passenger from terminal T to station St_m and from St_m to T is:

$$\begin{aligned} t_{Tm} &= t_{T0} + m \times t_2^* + t_w \\ &= \frac{L_B}{s_B} + \frac{mL_A}{nc_2 s_A} + \alpha \end{aligned}$$

Note that directional difference is eliminated and frequency of train does not affect to the travel time. As a result, the total return travel time for them is:

$$t_2 = 2t_{Tm} = \frac{2L_B}{s_B} + \frac{2mL_A}{nc_2 s_A} + 2\alpha$$

Change of travel time by the project is:

$$\Delta t_2 = t_2 - t_0 = \frac{2(1-c_2)mL_A}{nc_2 s_A} + 2\alpha - \frac{1}{4F_A} - \frac{1}{4F_B}$$

<u>Time savings:</u>

Within Line A

$$-\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_2)L_A}{nc_2 s_A}$$

For transfer time reduction

$$-R_{T0}(2\alpha - \frac{1}{4F_A} - \frac{1}{4F_B})$$

[•] Yamagata and Akita Shinkansen equipment run on Tohoku Shinkansen's conventional facility connected with conventional equipment of Tohoku Shinkansen, and connection / disconnection of trains are needed at Fukushima and Morioka station respectively.

[••] Approximately 3 minutes in the JR East case.

Total

$$TS_2 = -\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_2)L_A}{nc_2 s_A} - R_{T0}(2\alpha - \frac{1}{4F_A} - \frac{1}{4F_B})$$

4.2.2.4 Case 3: Conventional Shinkansen

If conventional Shinkansen is constructed on the Line A, it is natural to regard it as extension of the Line B. While the maximum speed and acceleration / deceleration rate are identical to trains on the Line B, the average speed of the Line A is not guaranteed as same as that of the Line B, since shorter station spacing might affect the average speed to some extent.

The average speed on route A will be improved. When the average speed increases by rate c_3, new unit travel time on route A is:

$$t_3^* = \frac{L_A}{n \times c_3 s_A}$$

<u>*Within Line A*</u>

For passengers from station St_l to St_m ($0 \leq l < m \leq n$), total travel time for return trip is:

$$t_3 = \frac{2(m-l)L_A}{nc_3 s_A}$$

Change of travel time by the project is:

$$\Delta t_3 = \frac{2(m-l)L_A}{nc_3 s_A} - \frac{2(m-l)L_A}{ns_A}$$
$$= \frac{2(1-c_3)(m-l)L_A}{nc_3 s_A}$$

<u>*For passengers using both line A and B*</u>

Now route A and route B can be regarded as one, and no transfer time at station St_0 is required. So total travel time for passenger from terminal T to station St_m and vice versa are identical and necessary time for return trip is:

$$t_3 = 2(t_{T0} + m \times t_3^*)$$
$$= \frac{2L_B}{s_B} + \frac{2mL_A}{nc_3 s_A}$$

Change of travel time by the project is:

$$\Delta t_3 = t_3 - t_0 = \frac{2(1-c_3)mL_A}{nc_3 s_A} - \frac{1}{4F_A} - \frac{1}{4F_B}$$

Time savings

Within Line A

$$-\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_3)L_A}{nc_3 s_A}$$

For transfer time reduction

$$-R_{T0}(-\frac{1}{4F_A} - \frac{1}{4F_B})$$

Total

$$TS_3 = -\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_3)L_A}{nc_3 s_A} - R_{T0}(-\frac{1}{4F_A} - \frac{1}{4F_B})$$

4.2.2.5 Case 4: Maglev

If Maglev is constructed to cover route A only, its characteristics is almost identical to the case 1 (incremental HSR) except superior speed because of no compatibility of equipment between line A and B. So in this case we assume Maglev to be constructed both on route A and B.

The average speed on route A will be improved. When the average speed increases by rate c_4, new unit travel time on route A is:

$$t_4^* = \frac{L_A}{n \times c_4 s_A}$$

Within Line A

For passengers from station St_l to St_m ($0 \le l < m \le n$), total travel time for return trip is:

$$t_4 = \frac{2(m-l)L_A}{nc_4 s_A}$$

Change of travel time by the project is:

$$\Delta t_4 = \frac{2(m-l)L_A}{nc_4 s_A} - \frac{2(m-l)L_A}{ns_A}$$
$$= \frac{2(1-c_4)(m-l)L_A}{nc_4 s_A}$$

For passengers using both line A and B

Note that the average speed on route B will also increase. When it increases by rate c_4^B, the total travel time for passenger from terminal T to station St_m and from St_m to T is:

$$t_4 = 2(t_{T0}^4 + m \times t_4^*)$$
$$= \frac{2L_B}{c_4^B s_B} + \frac{2mL_A}{nc_4 s_A}$$

Change of travel time by the project is:

$$\Delta t_4 = t_4 - t_0 = \frac{2L_B(1-c_4^B)}{c_4^B s_B} + \frac{2(1-c_4)mL_A}{nc_4 s_A} - \frac{1}{4F_A} - \frac{1}{4F_B}$$

Time savings

Within Line A $-\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_4)L_A}{nc_4 s_A}$

Within Line B $-R_{T0} \times \frac{2(1-c_4^B)L_B}{c_4^B s_B}$

For transfer time reduction $-R_{T0}(-\frac{1}{4F_A} - \frac{1}{4F_B})$

Total

$$TS_4 = -\sum_{i=0}^{n-1} R_{i(i+1)} \frac{2(1-c_4)L_A}{nc_4 s_A} - R_{T0} \times \frac{2(1-c_4^B)L_B}{c_4^B s_B} - R_{T0}(-\frac{1}{4F_A} - \frac{1}{4F_B})$$

4.2.2.6 Summary

In this model 2, the impacts of several HSR technologies on travel time are analyzed. In the next section, we will create a hypothetical region to utilize these models.

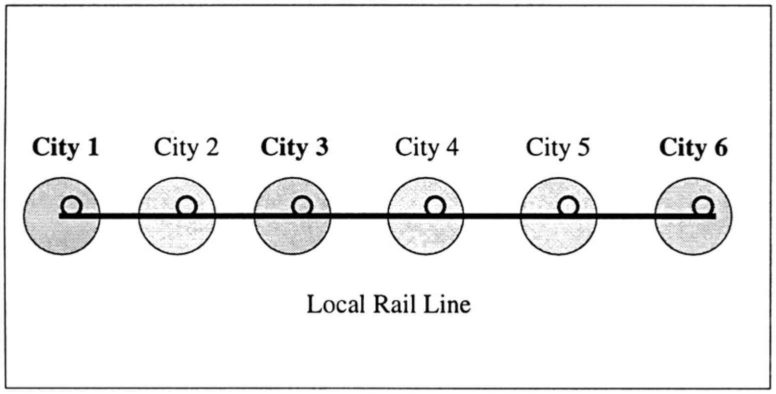
4.3 A Hypothetical Region - Transportation Corridor

In the previous section, we analyzed impacts of various HSR technologies on travel time. To understand the magnitude of impacts by various technologies, we develop two hypothetical regions and perform a scenario analysis for high-speed rail implementation with various level of technologies including Maglev and various operational plans. We will analyze each scenario not only for the entire corridor but for the each station.

4.3.1 Region 1

In Region 1, we assume a hypothetical region that consists of 6 cities. Geographically this region forms a corridor, and all cities are connected by a commercial rail service. (See Figure 4-5) However, this rail service is conventional-type and relatively slow. We assume that this rail service is to be upgraded.

Figure 4-5: Hypothetical Region 1



[assumptions]

- Distance between adjacent cities is assumed all identical. We assume the distance between two adjacent stations is 60 km for all set of cities. Note that this distance is enough for a Maglev, the fastest option to reach its maximum speed between stations. (See Table 5-2)
- All passengers are supposed to make return trip on the same transportation mode: however, the time saving benefit is calculated for one way.
- Three types of technology are available: Incremental HSR, Full Shinkansen, and Maglev. Each technology is summarized in Table 4-5. Note that Mini Shinkansen option is not con-

sidered in this region, because it is identical to Incremental HSR when no existing Full Shinkansen route is connected. The Mini Shinkansen option will be considered in the Region 2.

- Incremental HSR shares the right-of-way with local trains but operate at a higher maximum speed. It shares the right-of-way with local trains so that no skipping intermediate stations is allowed. Trains stop all the stations and this can be regarded as speed-up of existing service.
- The others, Full Shinkansen and Maglev, require a dedicated right-of-way and do not necessarily have to stop all the cities en route. Note that the existing local line also remains to guarantee rail service for the cities skipped.
- Passengers already know the timetable before coming to station so that waiting time to board first train of his/her trip can be neglected.
- Dwell time for trains at any intermediate stations is set to 1 minute.
- If a traveler has to make a physical transfer between high-speed rail and conventional rail service, 20 minutes for transfer and waiting next train is added to the overall travel time.

Table 4-5: Available Technologies

Technology	Maximum Speed km/h	Maximum Speed m/s	Acceleration ratio m/s/s	Acceleration 0-100 km/h sec	Deceleration ratio m/s/s	Deceleration 0-100 km/h sec	Minimum distance to reach maximum speed (km)
Local	90	25.00	0.3	93	0.3	93	2.08
Incremental	150	41.67	0.3	93	0.3	93	5.79
Full Shinkansen	300	83.33	0.3	93	0.3	93	23.15
Maglev	450	125.00	0.3	93	0.3	93	52.08

At present, rail travel time between cities are as follows;

Table 4-6: Status quo Travel Time*

city from	city to	distance (km)	travel time (minutes)
1	2	60	35
1	3	120	70
1	4	180	106
1	5	240	142
1	6	300	178
2	3	60	35
2	4	120	70
2	5	180	106
2	6	240	142
3	4	60	35
3	5	120	70
3	6	180	106
4	5	60	35
4	6	120	70
5	6	60	35

We make three assumptions for the travel demand on the route: Case(1): demand is equal for all pairs of origin and destination, Case(2): demand between City 1 and 3, 1 and 6, and 3 and 6 are relatively higher and Case(3): demand between City 1 and 6 is higher. We also make three operational plans for skipping stations: (1) stop at all stations, (2) stop only at city 1, 3, and 6, (3) stop only at city 1 and 6. Note that the pattern of station skipping will apply to every HSR train. Also note that the skipping here applies only to the HSR and Maglev, but not to the Incremental HSR, because the Incremental HSR shares the right-of-way with existing local trains. We assume that the Incremental HSR stops all stations in all cases.

We make 9 different scenarios for analysis. (See Table 4-7)

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* Travel time includes 1 minute dwell time at intermediate stations.

Table 4-7: Nine Scenarios (Three Operation Plan and Three Demand Patterns)

	HSR (including Maglev) stops at all stations	HSR (including Maglev) stops at only City 1,3,6	HSR (including Maglev) stops at only City 1 and 6
Demand is even; each O-D pair has the same amount of travel demand	Scenario #1	Scenario #2	Scenario #3
Demand between City 1, 3, 6 is higher than other O-D pairs	Scenario #4	Scenario #5	Scenario #6
Demand between City 1 and 6 is extremely higher than other O-D pairs	Scenario #7	Scenario #8	Scenario #9

The assumption in travel demand for each origin-destination pair is summarized in the following table. Note that the total travel demand is set to 30,000 for each scenario.

Table 4-8: Daily OD-Demand for each Scenario (Daily, hundreds)

City from	City to	Scenario #1	Scenario #2	Scenario #3	Scenario #4	Scenario #5	Scenario #6	Scenario #7	Scenario #8	Scenario #9
1	2	20	20	20	10	10	10	10	10	10
1	3	20	20	20	60	60	60	10	10	10
1	4	20	20	20	10	10	10	10	10	10
1	5	20	20	20	10	10	10	10	10	10
1	6	20	20	20	60	60	60	160	160	160
2	3	20	20	20	10	10	10	10	10	10
2	4	20	20	20	10	10	10	10	10	10
2	5	20	20	20	10	10	10	10	10	10
2	6	20	20	20	10	10	10	10	10	10
3	4	20	20	20	10	10	10	10	10	10
3	5	20	20	20	10	10	10	10	10	10
3	6	20	20	20	60	60	60	10	10	10
4	5	20	20	20	10	10	10	10	10	10
4	6	20	20	20	10	10	10	10	10	10
5	6	20	20	20	10	10	10	10	10	10
total	demand	300	300	300	300	300	300	300	300	300

We analyzed the travel time savings for each scenario and summarized for each stations. Here the time savings shows the savings for one direction, although all passengers make return trip. Following is the results of the scenario analysis. First, the time savings of nine cases are presented, and total time savings for the entire corridor and time savings for each station are analyzed.

Scenario #1: **OD demand is even.**
HSR stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	84	200
1	4	180	126	200
1	5	240	169	200
1	6	300	211	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	169	200
3	4	60	41	200
3	5	120	84	200
3	6	180	126	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
			total travel time (hours)	4895
			time savings (hours)	0

(2) Incremental HSR (150 km/h)

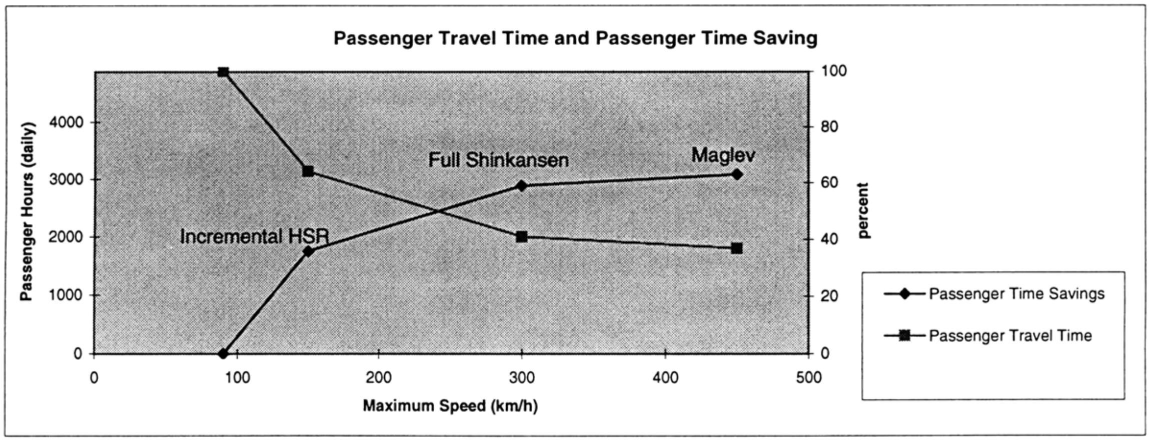
city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	26	200
1	3	120	54	200
1	4	180	81	200
1	5	240	108	200
1	6	300	136	200
2	3	60	26	200
2	4	120	54	200
2	5	180	81	200
2	6	240	108	200
3	4	60	26	200
3	5	120	54	200
3	6	180	81	200
4	5	60	26	200
4	6	120	54	200
5	6	60	26	200
			total travel time (hours)	3137
			time savings (hours)	1759

(3) Full Shinkansen (300 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	17	200
1	3	120	34	200
1	4	180	52	200
1	5	240	70	200
1	6	300	87	200
2	3	60	17	200
2	4	120	34	200
2	5	180	52	200
2	6	240	70	200
3	4	60	17	200
3	5	120	34	200
3	6	180	52	200
4	5	60	17	200
4	6	120	34	200
5	6	60	17	200
			total travel time (hours)	2007
			time savings (hours)	2889

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	15	200
1	3	120	31	200
1	4	180	47	200
1	5	240	63	200
1	6	300	79	200
2	3	60	15	200
2	4	120	31	200
2	5	180	47	200
2	6	240	63	200
3	4	60	15	200
3	5	120	31	200
3	6	180	47	200
4	5	60	15	200
4	6	120	31	200
5	6	60	15	200
			total travel time (hours)	1810
			time savings (hours)	3085



Scenario#2: **OD demand is even.**
HSR stops only at station 1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	84	200
1	4	180	126	200
1	5	240	169	200
1	6	300	211	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	169	200
3	4	60	41	200
3	5	120	84	200
3	6	180	126	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
			total travel time (hours)	4895
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

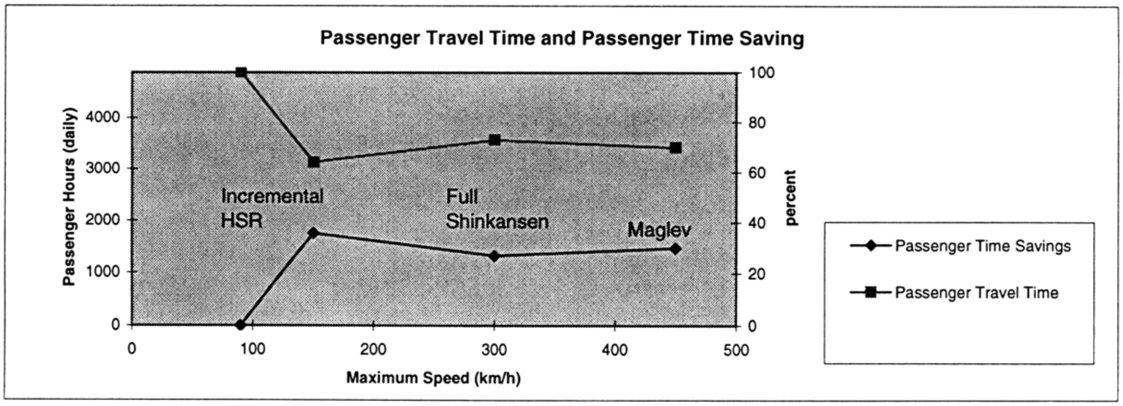
city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	29	200
1	4	180	90	200
1	5	240	133	200
1	6	300	70	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	113	200
3	4	60	41	200
3	5	120	84	200
3	6	180	52	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
			total travel time (hours)	3571
			time savings (hours)	1325

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	26	200
1	3	120	54	200
1	4	180	81	200
1	5	240	108	200
1	6	300	136	200
2	3	60	26	200
2	4	120	54	200
2	5	180	81	200
2	6	240	108	200
3	4	60	26	200
3	5	120	54	200
3	6	180	81	200
4	5	60	26	200
4	6	120	54	200
5	6	60	26	200
			total travel time (hours)	3137
			time savings (hours)	1759

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	23	200
1	4	180	84	200
1	5	240	127	200
1	6	300	55	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	108	200
3	4	60	41	200
3	5	120	84	200
3	6	180	47	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
			total travel time (hours)	3427
			time savings (hours)	1468



Scenario#3: **OD demand is even.**
HSR stops only at station 1, 6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	84	200
1	4	180	126	200
1	5	240	169	200
1	6	300	211	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	169	200
3	4	60	41	200
3	5	120	84	200
3	6	180	126	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
		total travel time (hours)		4895
		time savings (hours)		0

(3) Full Shinkansen (300 km/h)

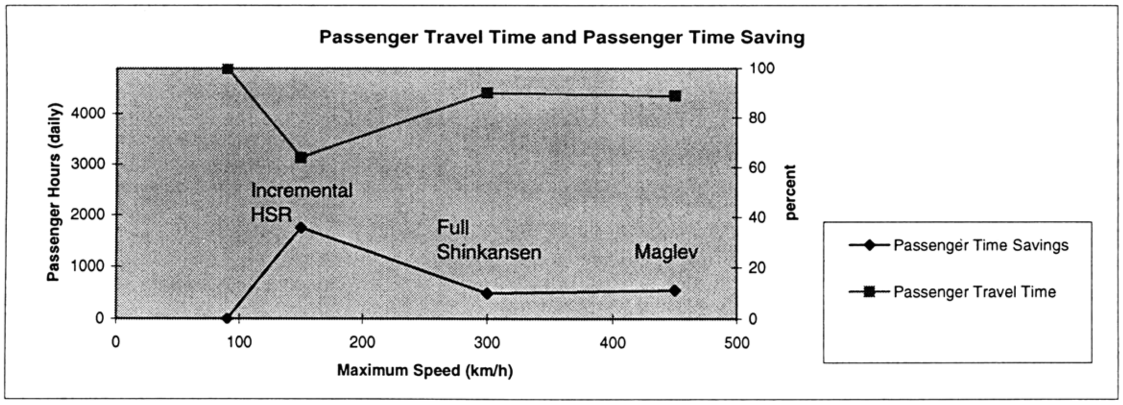
city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	84	200
1	4	180	126	200
1	5	240	169	200
1	6	300	65	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	169	200
3	4	60	41	200
3	5	120	84	200
3	6	180	126	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
		total travel time (hours)		4408
		time savings (hours)		488

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	26	200
1	3	120	54	200
1	4	180	81	200
1	5	240	108	200
1	6	300	136	200
2	3	60	26	200
2	4	120	54	200
2	5	180	81	200
2	6	240	108	200
3	4	60	26	200
3	5	120	54	200
3	6	180	81	200
4	5	60	26	200
4	6	120	54	200
5	6	60	26	200
		total travel time (hours)		3137
		time savings (hours)		1759

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	200
1	3	120	84	200
1	4	180	126	200
1	5	240	169	200
1	6	300	47	200
2	3	60	41	200
2	4	120	84	200
2	5	180	126	200
2	6	240	169	200
3	4	60	41	200
3	5	120	84	200
3	6	180	126	200
4	5	60	41	200
4	6	120	84	200
5	6	60	41	200
		total travel time (hours)		4349
		time savings (hours)		547



Scenario #4: **OD demand is higher among city 1, 3, 6.**
HSR stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	600
1	4	180	126	100
1	5	240	169	100
1	6	300	211	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	5955
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

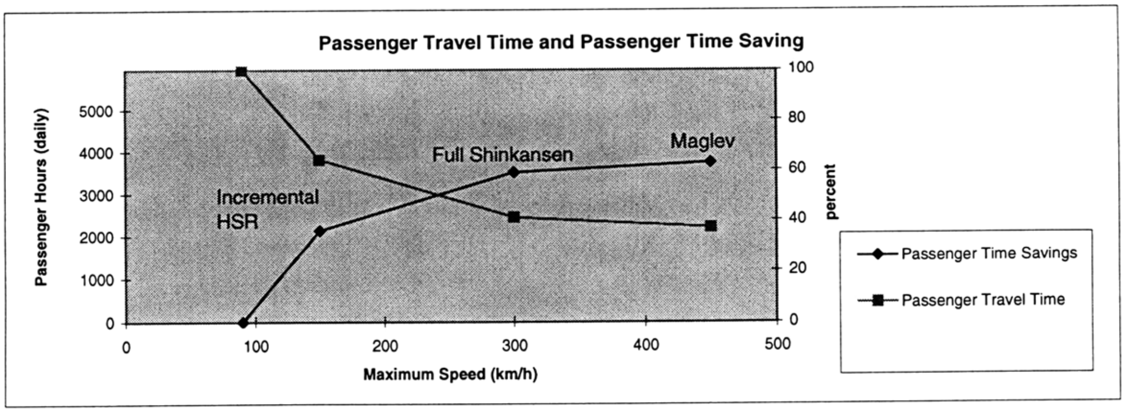
city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	17	100
1	3	120	34	600
1	4	180	52	100
1	5	240	70	100
1	6	300	87	600
2	3	60	17	100
2	4	120	34	100
2	5	180	52	100
2	6	240	70	100
3	4	60	17	100
3	5	120	34	100
3	6	180	52	600
4	5	60	17	100
4	6	120	34	100
5	6	60	17	100
			total travel time (hours)	2448
			time savings (hours)	3508

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	26	100
1	3	120	54	600
1	4	180	81	100
1	5	240	108	100
1	6	300	136	600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	600
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	3820
			time savings (hours)	2135

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	15	100
1	3	120	31	600
1	4	180	47	100
1	5	240	63	100
1	6	300	79	600
2	3	60	15	100
2	4	120	31	100
2	5	180	47	100
2	6	240	63	100
3	4	60	15	100
3	5	120	31	100
3	6	180	47	600
4	5	60	15	100
4	6	120	31	100
5	6	60	15	100
			total travel time (hours)	2209
			time savings (hours)	3746



Scenario#5: **OD demand is higher among city 1, 3, 6.**
HSR stops only at station 1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	600
1	4	180	126	100
1	5	240	169	100
1	6	300	211	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	5955
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

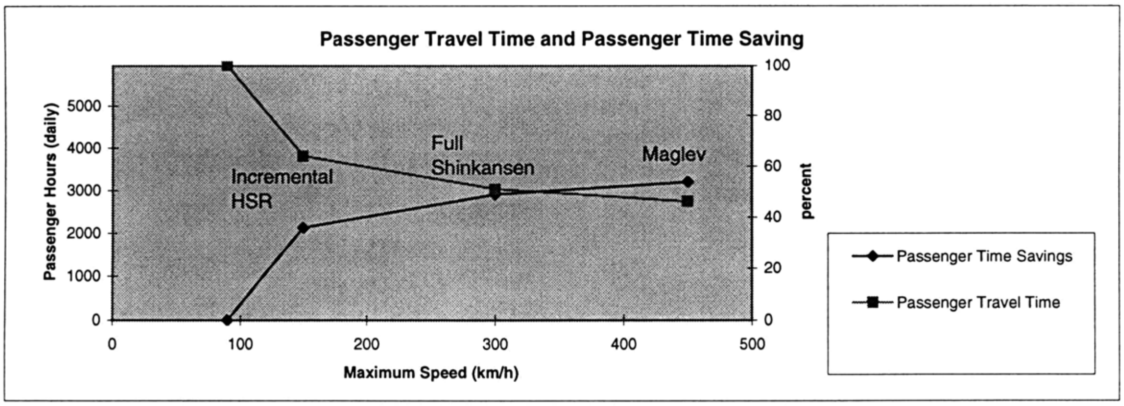
city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	29	600
1	4	180	90	100
1	5	240	133	100
1	6	300	70	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	113	100
3	4	60	41	100
3	5	120	84	100
3	6	180	52	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	3042
			time savings (hours)	2913

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	26	100
1	3	120	54	600
1	4	180	81	100
1	5	240	108	100
1	6	300	136	600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	600
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	3820
			time savings (hours)	2135

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	23	600
1	4	180	84	100
1	5	240	127	100
1	6	300	55	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	108	100
3	4	60	41	100
3	5	120	84	100
3	6	180	47	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	2752
			time savings (hours)	3203



Scenario#6: **OD demand is higher among city 1, 3, 6.**
HSR stops only at station 1, 6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	600
1	4	180	126	100
1	5	240	169	100
1	6	300	211	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	5955
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

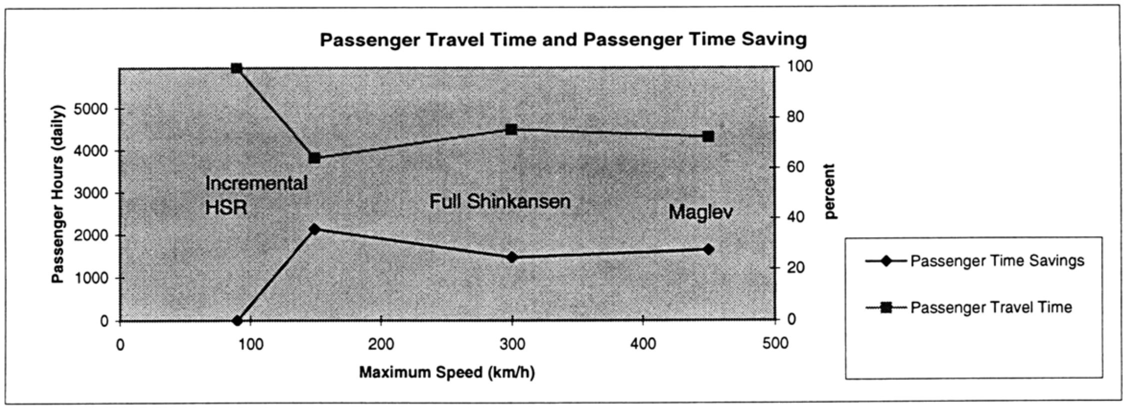
city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	84	600
1	4	180	126	100
1	5	240	169	100
1	6	300	65	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	4492
			time savings (hours)	1463

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	26	100
1	3	120	54	600
1	4	180	81	100
1	5	240	108	100
1	6	300	136	600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	600
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	3820
			time savings (hours)	2135

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	84	600
1	4	180	126	100
1	5	240	169	100
1	6	300	47	600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	600
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	4315
			time savings (hours)	1640



Scenario #7: **OD demand is higher between city 1 and 6.**
HSR stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	100
1	4	180	126	100
1	5	240	169	100
1	6	300	211	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	7721
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

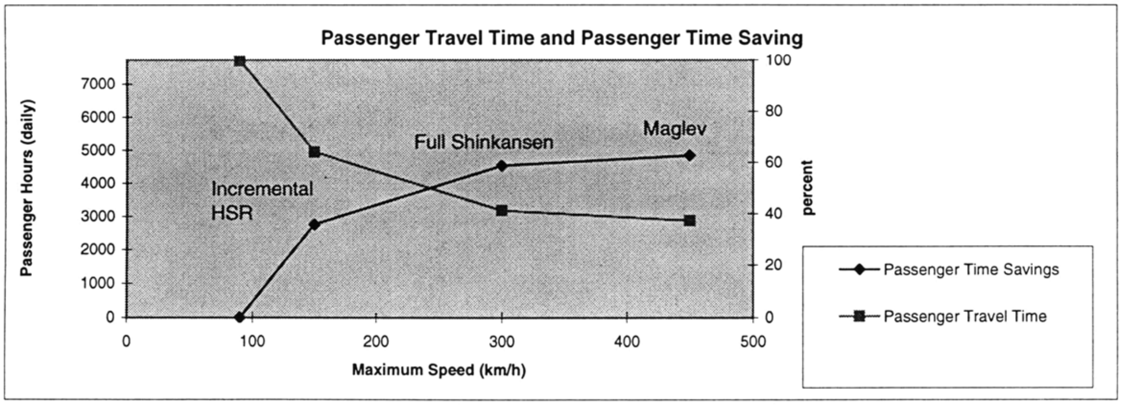
city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	17	100
1	3	120	34	100
1	4	180	52	100
1	5	240	70	100
1	6	300	87	1600
2	3	60	17	100
2	4	120	34	100
2	5	180	52	100
2	6	240	70	100
3	4	60	17	100
3	5	120	34	100
3	6	180	52	100
4	5	60	17	100
4	6	120	34	100
5	6	60	17	100
			total travel time (hours)	3182
			time savings (hours)	4539

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	26	100
1	3	120	54	100
1	4	180	81	100
1	5	240	108	100
1	6	300	136	1600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	100
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	4958
			time savings (hours)	2764

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	15	100
1	3	120	31	100
1	4	180	47	100
1	5	240	63	100
1	6	300	79	1600
2	3	60	15	100
2	4	120	31	100
2	5	180	47	100
2	6	240	63	100
3	4	60	15	100
3	5	120	31	100
3	6	180	47	100
4	5	60	15	100
4	6	120	31	100
5	6	60	15	100
			total travel time (hours)	2873
			time savings (hours)	4848



Scenario#8: **OD demand is higher between city 1 and 6.**
HSR stops only at station 1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	100
1	4	180	126	100
1	5	240	169	100
1	6	300	211	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	7721
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

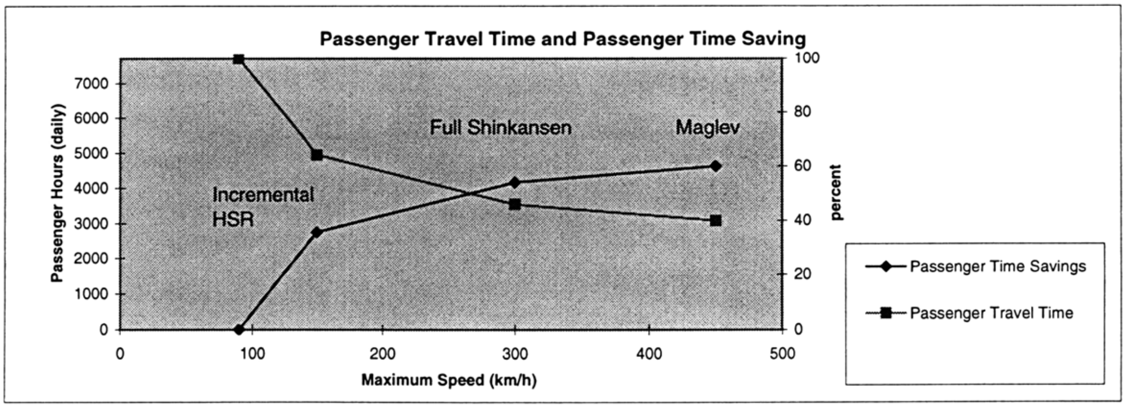
city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	29	100
1	4	180	90	100
1	5	240	133	100
1	6	300	70	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	113	100
3	4	60	41	100
3	5	120	84	100
3	6	180	52	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	3542
			time savings (hours)	4179

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	26	100
1	3	120	54	100
1	4	180	81	100
1	5	240	108	100
1	6	300	136	1600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	100
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	4958
			time savings (hours)	2764

(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	23	100
1	4	180	84	100
1	5	240	127	100
1	6	300	55	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	108	100
3	4	60	41	100
3	5	120	84	100
3	6	180	47	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	3086
			time savings (hours)	4636



Scenario#9: **OD demand is higher between city 1 and 6.**
HSR stops only at station 1, 6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	pass. demand
1	2	60	41	100
1	3	120	84	100
1	4	180	126	100
1	5	240	169	100
1	6	300	211	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	7721
			time savings (hours)	0

(3) Full Shinkansen (300 km/h)

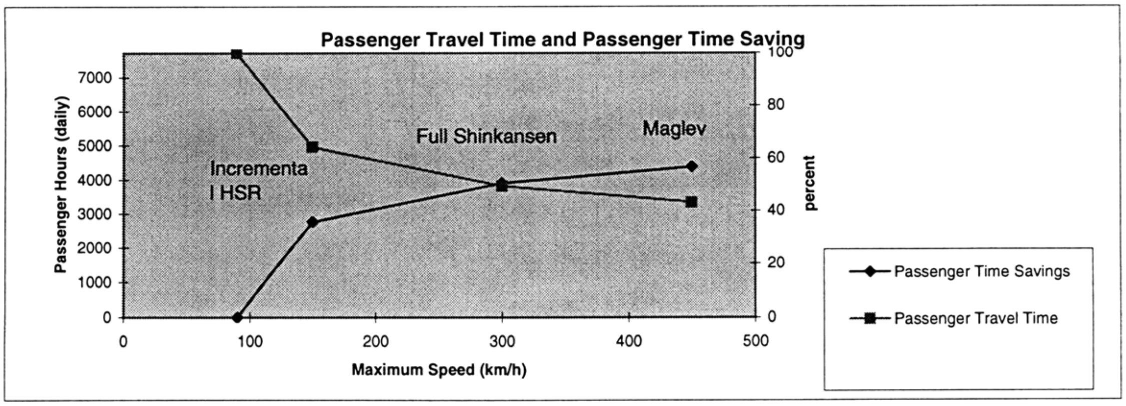
city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	84	100
1	4	180	126	100
1	5	240	169	100
1	6	300	65	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	3820
			time savings (hours)	3902

(2) Incremental HSR (150 km/h)

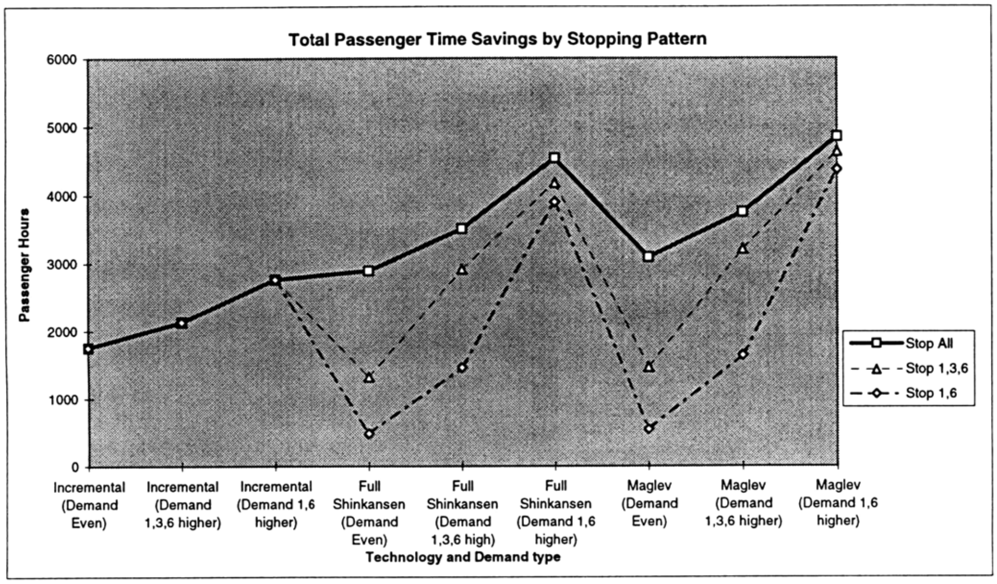
city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	26	100
1	3	120	54	100
1	4	180	81	100
1	5	240	108	100
1	6	300	136	1600
2	3	60	26	100
2	4	120	54	100
2	5	180	81	100
2	6	240	108	100
3	4	60	26	100
3	5	120	54	100
3	6	180	81	100
4	5	60	26	100
4	6	120	54	100
5	6	60	26	100
			total travel time (hours)	4958
			time savings (hours)	2764

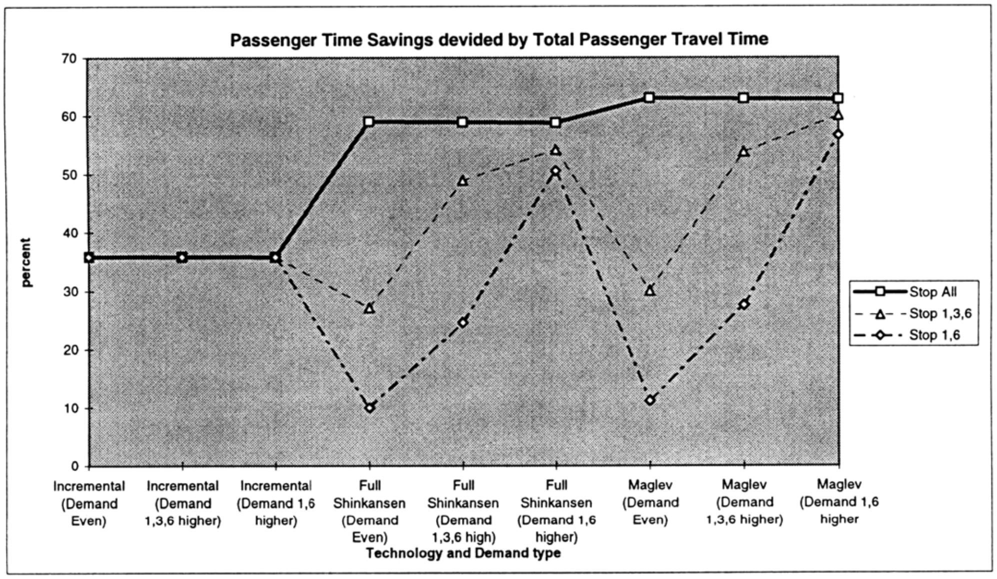
(4) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	demand (hundreds)
1	2	60	41	100
1	3	120	84	100
1	4	180	126	100
1	5	240	169	100
1	6	300	47	1600
2	3	60	41	100
2	4	120	84	100
2	5	180	126	100
2	6	240	169	100
3	4	60	41	100
3	5	120	84	100
3	6	180	126	100
4	5	60	41	100
4	6	120	84	100
5	6	60	41	100
			total travel time (hours)	3348
			time savings (hours)	4373



Total Passenger Time Savings by Stopping Pattern



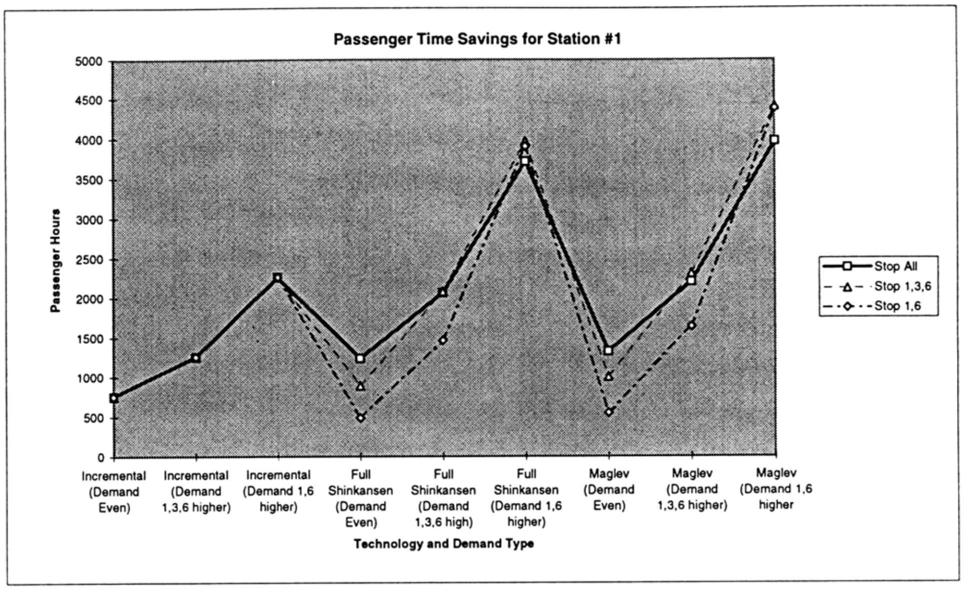


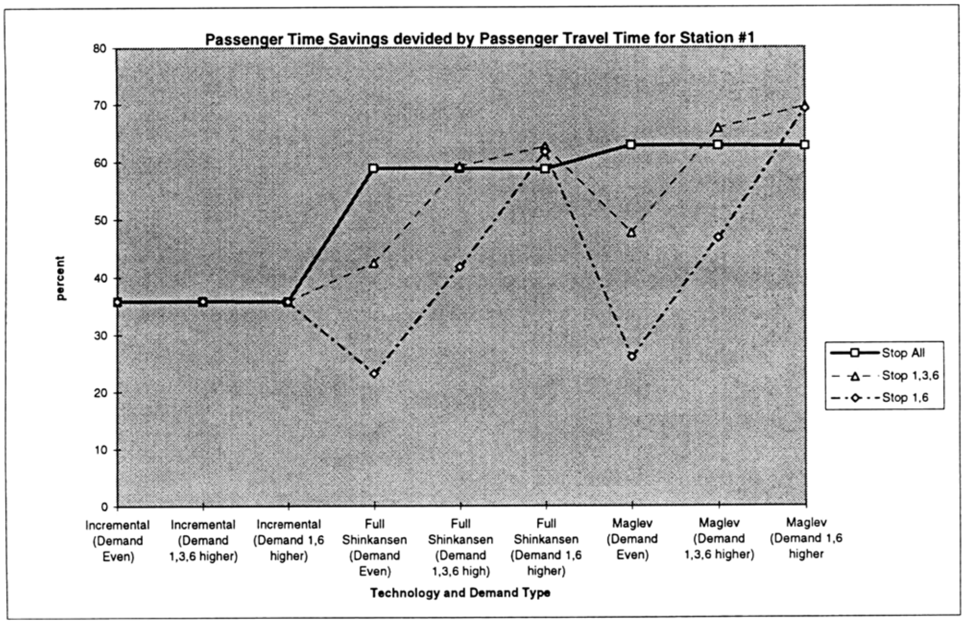
Total Passenger Travel Time (Status quo)	hour
Demand Even	4895
Demand 1,3,6 higher	5955
Demand 1,6 higher	7721

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	1759	35.93	1759	35.93	1759	35.93
Incremental (Demand 1,3,6 higher)	2135	35.86	2135	35.86	2135	35.86
Incremental (Demand 1,6 higher)	2764	35.79	2764	35.79	2764	35.79
Full Shinkansen (Demand Even)	2889	59.01	1325	27.06	488	9.96
Full Shinkansen (Demand 1,3,6 high)	3508	58.90	2913	48.92	1463	24.57
Full Shinkansen (Demand 1,6 higher)	4539	58.79	4179	54.13	3902	50.53
Maglev (Demand Even)	3085	63.03	1468	30.00	547	11.17
Maglev (Demand 1,3,6 higher)	3746	62.91	3203	53.78	1640	27.54
Maglev (Demand 1,6 higher)	4848	62.79	4636	60.04	4373	56.64

Station #1



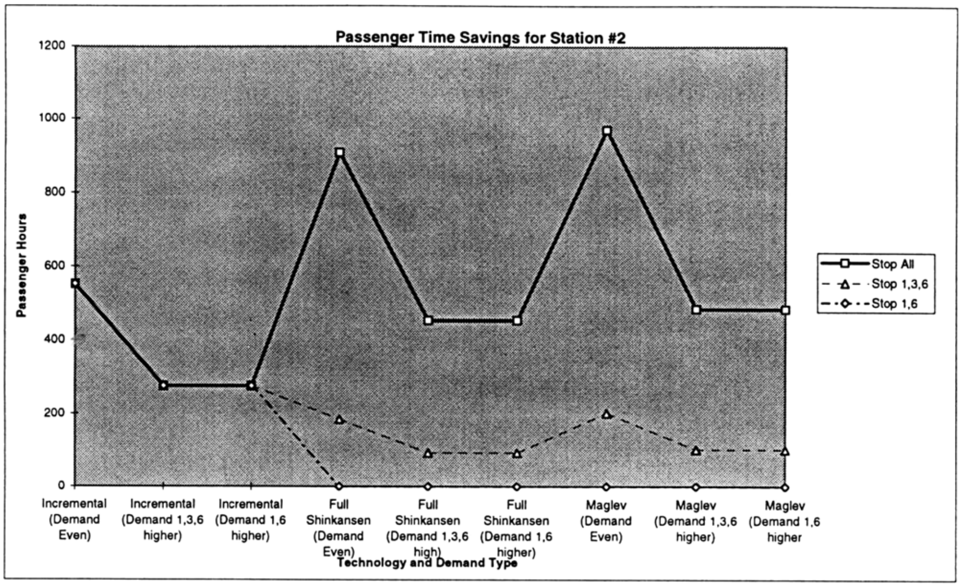


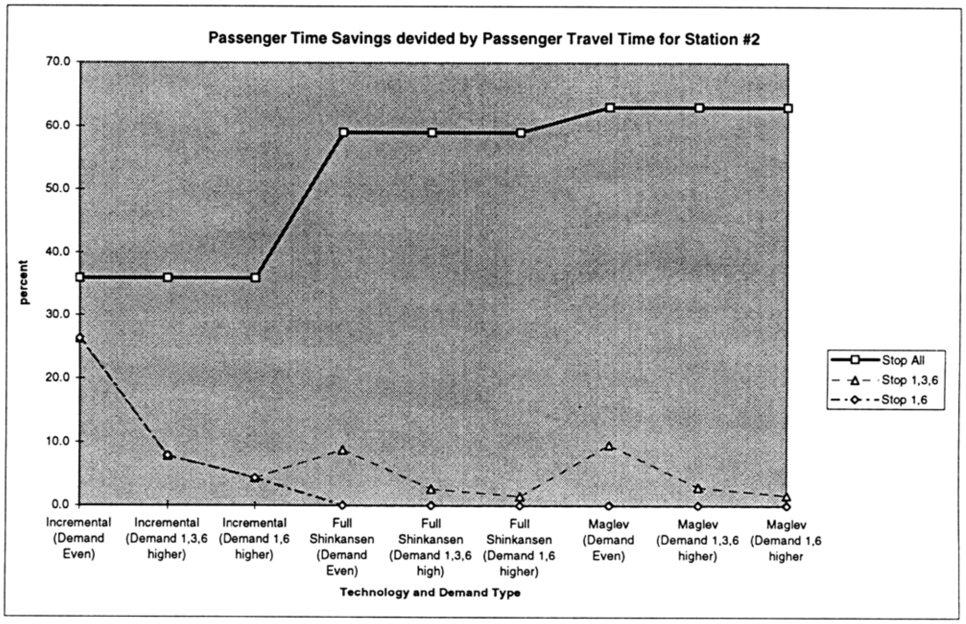
Total Passenger Travel Time (Status quo)	hour
Demand Even	2103
Demand 1,3,6 higher	3507
Demand 1,6 higher	6325

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	754	35.8	754	35.8	754	35.8
Incremental (Demand 1,3,6 higher)	1256	35.8	1256	35.8	1256	35.8
Incremental (Demand 1,6 higher)	2261	35.7	2261	35.7	2261	35.7
Full Shinkansen (Demand Even)	1238	58.9	892	42.4	488	23.2
Full Shinkansen (Demand 1,3,6 high)	2063	58.8	2078	59.2	1463	41.7
Full Shinkansen (Demand 1,6 higher)	3714	58.7	3963	62.7	3902	61.7
Maglev (Demand Even)	1322	62.9	1002	47.7	547	26.0
Maglev (Demand 1,3,6 higher)	2204	62.8	2308	65.8	1640	46.8
Maglev (Demand 1,6 higher	3967	62.7	4402	69.6	4373	69.1

Station #2



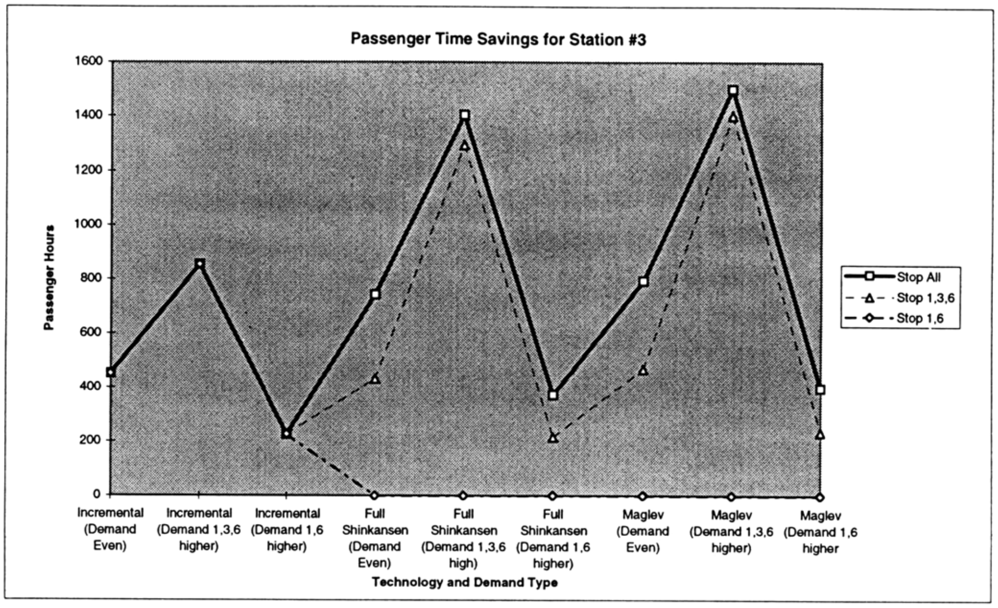


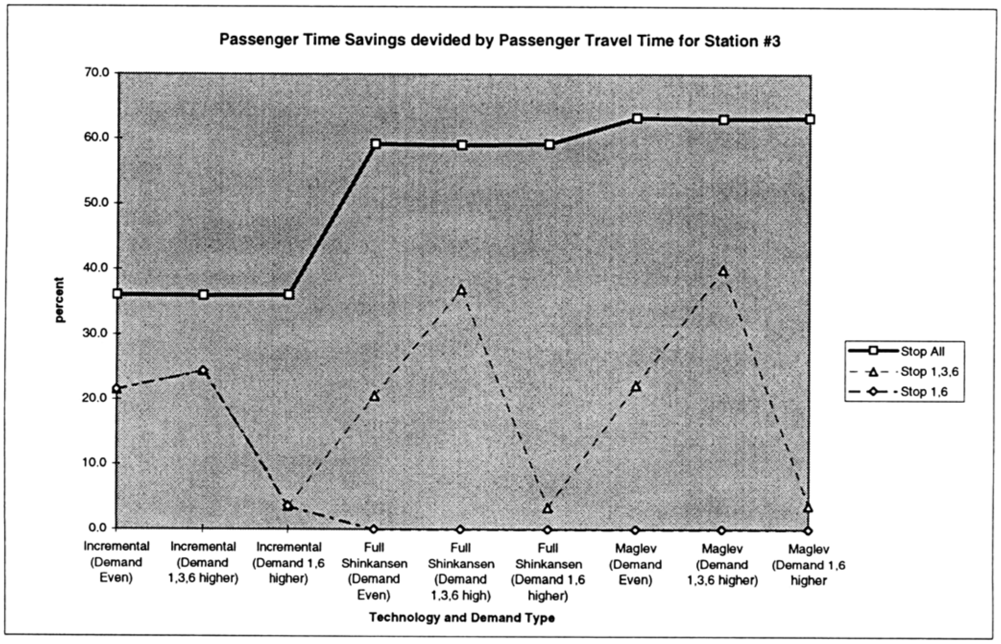
Total Passenger Travel Time (Status quo)	**hour**
Demand Even	1538
Demand 1,3,6 higher	769
Demand 1,6 higher	769

Passenger Time Savings

	Stop All		**Stop 1,3,6**		**Stop 1,6**	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	553	35.9	553	26.3	553	26.3
Incremental (Demand 1,3,6 higher)	276	35.9	276	7.9	276	7.9
Incremental (Demand 1,6 higher)	276	35.9	276	4.4	276	4.4
Full Shinkansen (Demand Even)	908	59.0	185	8.8	0	0.0
Full Shinkansen (Demand 1,3,6 high)	454	59.0	93	2.6	0	0.0
Full Shinkansen (Demand 1,6 higher)	454	59.0	93	1.5	0	0.0
Maglev (Demand Even)	970	63.1	202	9.6	0	0.0
Maglev (Demand 1,3,6 higher)	485	63.1	101	2.9	0	0.0
Maglev (Demand 1,6 higher	485	63.1	101	1.6	0	0.0

Station #3



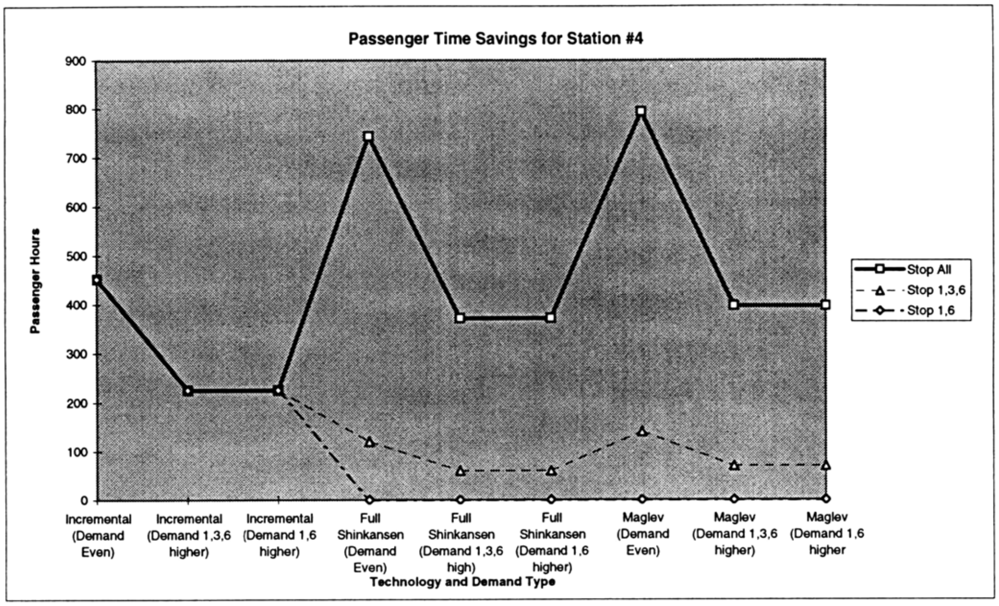


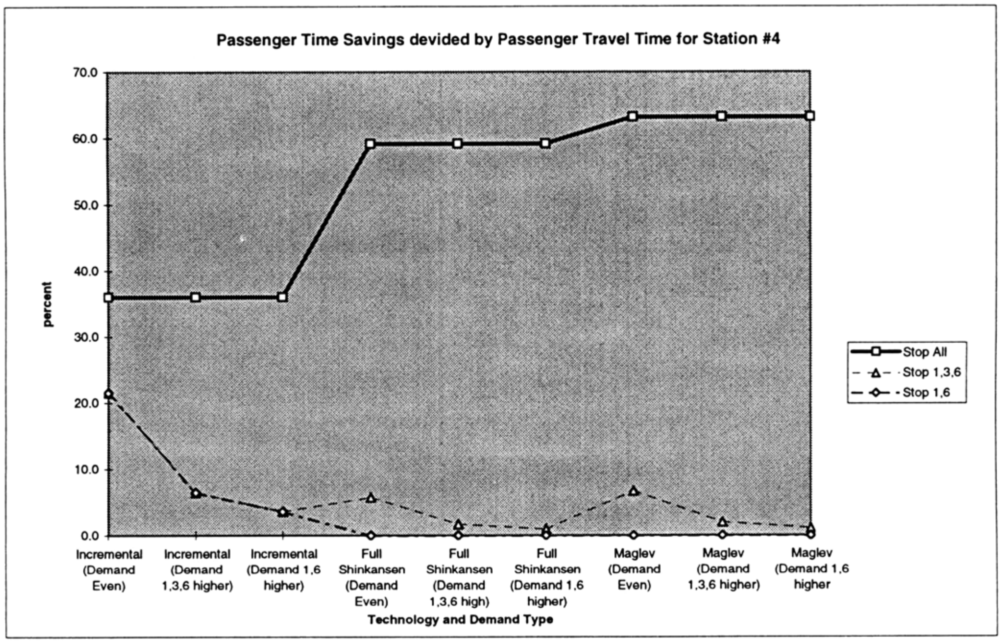
Total Passenger Travel Time (Status quo)	hour
Demand Even	1255
Demand 1,3,6 higher	2377
Demand 1,6 higher	628

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	452	36.0	452	21.5	452	21.5
Incremental (Demand 1,3,6 higher)	854	35.9	854	24.4	854	24.4
Incremental (Demand 1,6 higher)	226	36.0	226	3.6	226	3.6
Full Shinkansen (Demand Even)	743	59.2	431	20.5	0	0.0
Full Shinkansen (Demand 1,3,6 high)	1403	59.0	1294	36.9	0	0.0
Full Shinkansen (Demand 1,6 higher)	371	59.2	216	3.4	0	0.0
Maglev (Demand Even)	793	63.2	467	22.2	0	0.0
Maglev (Demand 1,3,6 higher)	1499	63.0	1402	40.0	0	0.0
Maglev (Demand 1,6 higher	397	63.2	234	3.7	0	0.0

Station #4


Passenger Time Savings for Station #4

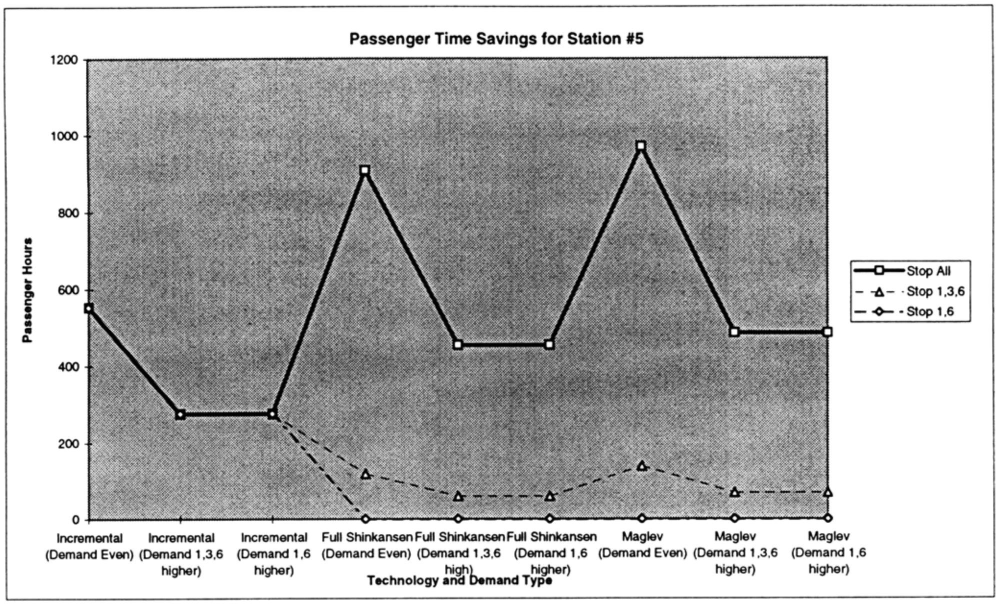

Passenger Time Savings devided by Passenger Travel Time for Station #4

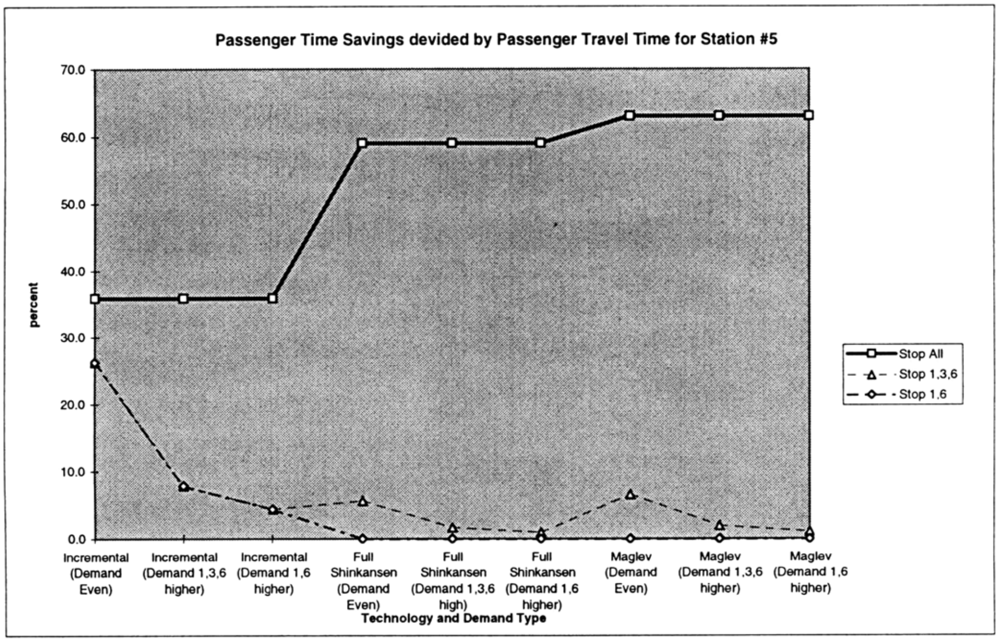
Total Passenger Travel Time (Status quo)	hour
Demand Even	1255
Demand 1,3,6 higher	628
Demand 1,6 higher	628

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	452	36.0	452	21.5	452	21.5
Incremental (Demand 1,3,6 higher)	226	36.0	226	6.4	226	6.4
Incremental (Demand 1,6 higher)	226	36.0	226	3.6	226	3.6
Full Shinkansen (Demand Even)	743	59.2	121	5.7	0	0.0
Full Shinkansen (Demand 1,3,6 high)	371	59.2	60	1.7	0	0.0
Full Shinkansen (Demand 1,6 higher)	371	59.2	60	1.0	0	0.0
Maglev (Demand Even)	793	63.2	141	6.7	0	0.0
Maglev (Demand 1,3,6 higher)	397	63.2	70	2.0	0	0.0
Maglev (Demand 1,6 higher	397	63.2	70	1.1	0	0.0

Station #5



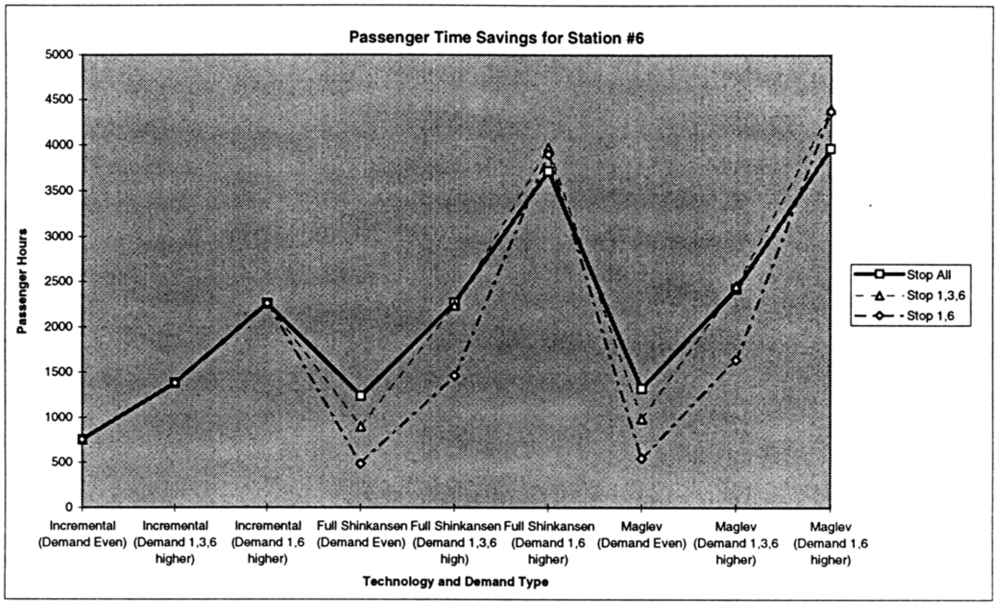


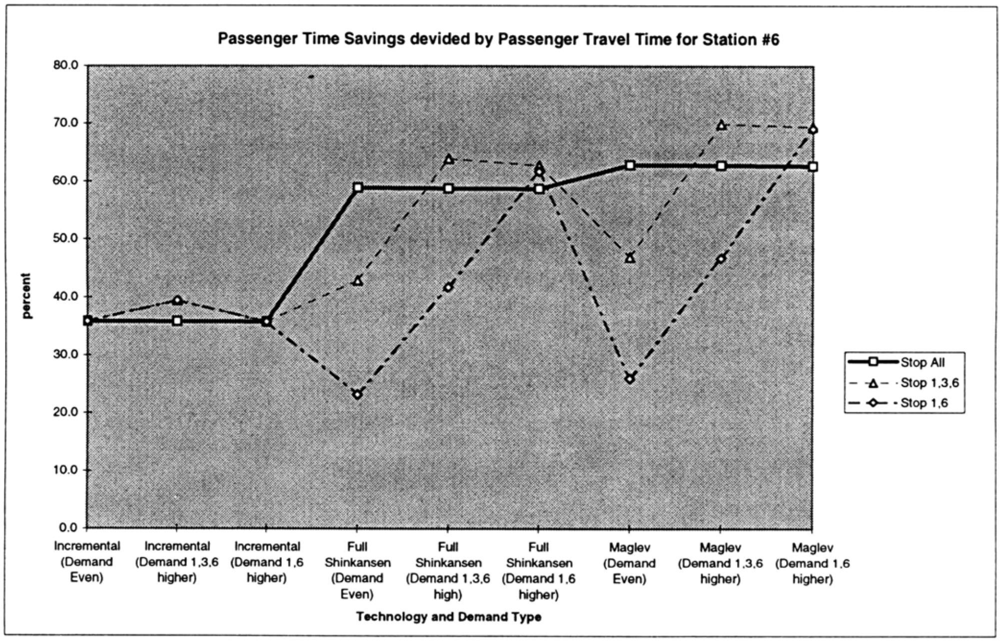
Total Passenger Travel Time (Status quo)	hour
Demand Even	1538
Demand 1,3,6 higher	769
Demand 1,6 higher	769

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	553	35.9	553	26.3	553	26.3
Incremental (Demand 1,3,6 higher)	276	35.9	276	7.9	276	7.9
Incremental (Demand 1,6 higher)	276	35.9	276	4.4	276	4.4
Full Shinkansen (Demand Even)	908	59.0	119	5.6	0	0.0
Full Shinkansen (Demand 1,3,6 high)	454	59.0	59	1.7	0	0.0
Full Shinkansen (Demand 1,6 higher)	454	59.0	59	0.9	0	0.0
Maglev (Demand Even)	970	63.1	139	6.6	0	0.0
Maglev (Demand 1,3,6 higher)	485	63.1	69	2.0	0	0.0
Maglev (Demand 1,6 higher)	485	63.1	69	1.1	0	0.0

Station #6





Total Passenger Travel Time (Status quo)	hour
Demand Even	2103
Demand 1,3,6 higher	3861
Demand 1,6 higher	6325

Passenger Time Savings

	Stop All		Stop 1,3,6		Stop 1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	754	35.8	754	35.8	754	35.8
Incremental (Demand 1,3,6 higher)	1382	35.8	1382	39.4	1382	39.4
Incremental (Demand 1,6 higher)	2261	35.7	2261	35.7	2261	35.7
Full Shinkansen (Demand Even)	1238	58.9	902	42.9	488	23.2
Full Shinkansen (Demand 1,3,6 high)	2270	58.8	2242	63.9	1463	41.7
Full Shinkansen (Demand 1,6 higher)	3714	58.7	3968	62.7	3902	61.7
Maglev (Demand Even)	1322	62.9	986	46.9	547	26.0
Maglev (Demand 1,3,6 higher)	2424	62.8	2455	70.0	1640	46.8
Maglev (Demand 1,6 higher)	3967	62.7	4395	69.5	4373	69.1

Findings:

- In the scenario #1, which assumes balanced OD demand between cities with trains stopping all stations, the technologies with higher maximum speed bears more time saving benefits. Maglev gains more time savings than HSR, which gains more than Incremental HSR. However, increase in time savings diminishes as the maximum speed increases. Generally construction cost of high-speed rail is tied directly to its maximum speed, and this fact implies that focusing only on the maximum speed is not enough for cost-effective strategy.

- In the scenario #2 and #3, which allow HSR and Maglev to skip stations, we see the time savings are less than the scenario #1 with all trains stopping all stations. The travel time between city 1,3, and 6 is shortened, but this marginal benefit can not cover the loss of the time savings by the passengers in city 2, 4, and 5, who enjoyed time savings in the scenario #1. In these cases, the incremental HSR, which stops all the stations, is the best strategy to maximize time savings. Note that the time saving of scenario #3 is less than that of scenario #2, because high-speed rail in scenario #3 is beneficial only to the city 1 and 6, while scenario #2 is beneficial to city 1, 3, and 6.

- In the scenario #4, #5, #6, where the travel demand is higher among city 1, 3, 6, the amount of time savings is larger than in the scenario #1, #2, #3, because the average travel length of a passenger is longer. Maglev and HSR are better than incremental HSR in the scenario #4 and #5. However, in the scenario #6 we see the savings become maximum when the incremental HSR is chosen, because the travel demand to city 3 is not served by HSR or Maglev in this scenario.

- In the scenario #7, #8, #9 with extremely high demand between city 1 and 6, the time savings of Maglev is the largest. It is noted that time savings in the scenario #7, which makes trains stop all the stations, is larger than those of the other two scenarios.

- When we focus on stopping pattern, the result shows that the strategy that allows all trains to stop all stations is most beneficial to the entire corridor in term of travel time, regardless of what demand pattern in the three is applied.

- When we focus on each station, the best strategy in stopping pattern might be different among stations. For the station 1 and 6, skipping stations might bear more time savings when travel demand between city 1 and 6 is much higher. On the other hand, for the station 2, 3, 4, 5, the strategy of stopping all stations is always better.

- When we focus on different technologies, we can say that the faster service generally bears more time savings. However, the marginal benefit by an advanced technology will decrease as maximum speed becomes higher, and the marginal benefit may not be large enough to cover the marginal cost, which would increase at higher rate.

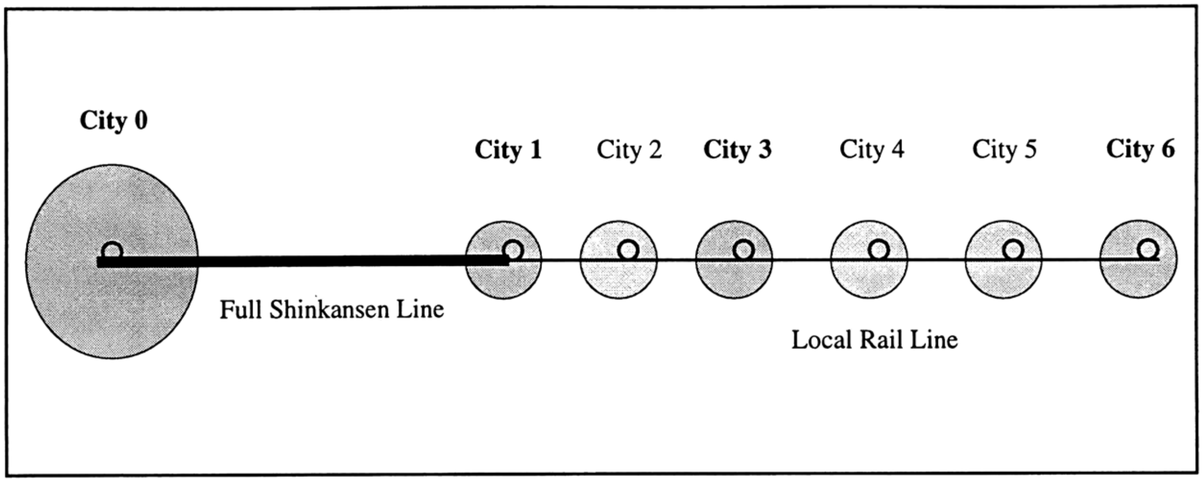
- In summary, faster service bears more time savings. It is also noted that the strategy that makes trains to stop all the stations generally gains more time savings for the whole corridor. Even when the demand between city 1 and city 6 is extremely higher as in the scenario #7, #8, #9, we see the total time saving is larger when trains stop at all stations.

Next, we analyze mixed routes with conventional rail track and Full Shinkansen track.

4.3.2 Region 2

We add a metropolitan "City 0" to the Region 1 and assume a Full Shinkansen line operating between City 0 and City 1. (See Figure 4-6) This region of seven cities forms a corridor geographically. All other assumptions in the Region 1 are also hold in this Region 2. We assume that the local rail service between City 1 and City 6 is to be upgraded. We introduce the concept of Mini Shinkansen in addition to three options in the Region 1, because in this case the utilization of existing Full Shinkansen line can be an important issue. We will see the difference in the magnitude of impacts by Incremental HSR and Mini Shinkansen in terms of elimination of transfer at City 1.

Figure 4-6: Hypothetical Region 2



[assumptions]

- Distance between adjacent cities is assumed all identical except that between City 0 and City 1. We assume that the distance between two adjacent stations is 60 km for all set of cities (1,2,3,4,5,6) and the distance between City 0 and City 1 is 400 km. Note that this distance of 60 km is enough for a Maglev, the fastest option to reach its maximum speed between stations.
- All passengers are supposed to make return trip on the same transportation mode: however, the time saving benefit is calculated for one way.
- Four types of technology are available: Incremental HSR, Mini Shinkansen, Full Shinkansen, and Maglev. Each technology is summarized in Table 4-9.
- Incremental HSR and Mini Shinkansen share the right-of-way with local trains but operate at a higher maximum speed. They share the right-of-way with local trains so that no skipping intermediate stations is allowed so that all trains stop all the stations.
- Mini Shinkansen can run on the dedicated Full Shinkansen tracks between City 0 and City 1 at the speed of Full Shinkansen. The transfer at City 1 is eliminated for passengers traveling between City 0 and City 2,3,4,5,6.
- Full Shinkansen can be regarded as an extension of the existing service between City 0 and City 1. It requires a dedicated right-of-way and do not necessarily have to stop all the cities en route, because the existing local line also remains to guarantee rail service for the cities skipped.

- Maglev requires a completely dedicated right-of-way. We assume that it will be constructed between City 0 and City 6. It requires a dedicated right-of-way and does not necessarily have to stop all the cities en route, because the existing local line also remains.
- Passengers already know the timetable before coming to station so that waiting time to board first train of their trip can be neglected.
- The dwell time for trains at intermediate stops is set to 1 minute.
- If a traveler has to make a physical transfer between different types of trains, 20 minutes is added to the overall travel time for making transfer and waiting the connecting train.

Table 4-9: Available Technologies

Technology	Maximum Speed		Acceleration		Deceleration		Minimum distance to reach maximum speed (km)
	km/h	m/s	ratio m/s/s	0-100 km/h sec	ratio m/s/s	0-100 km/h sec	
Local	90	25.00	0.3	93	0.3	93	2.08
Incremental	150	41.67	0.3	93	0.3	93	5.79
Mini Shinkansen	150	41.67	0.3	93	0.3	93	5.79
HSR	300	83.33	0.3	93	0.3	93	23.15
Maglev	450	125.00	0.3	93	0.3	93	52.08

At present, rail travel time between cities are as follows;

Table 4-10: Status quo Travel Time in Region 2[*]

city from	city to	distance (km)	travel time (minutes)
0	1	400	85
0	2	460	140
0	3	520	175
0	4	580	211
0	5	640	147
0	6	700	283
1	2	60	35
1	3	120	70
1	4	180	106
1	5	240	142
1	6	300	178
2	3	60	35
2	4	120	70
2	5	180	106
2	6	240	142
3	4	60	35
3	5	120	70
3	6	180	106
4	5	60	35
4	6	120	70
5	6	60	35

We make three assumptions for the travel demand on the route: Case(1): demand is equal for all pairs of origin and destination, Case(2): demand between City 0 and 1, 0 and 3, 0 and 6, 1 and 3, 1 and 6, and 3 and 6 are relatively higher, and Case(3): demand between City 0 and 1, 0 and 6, 1 and 6 are higher. We also make three operational plans for skipping stations: (1) stop at all stations, (2) stop only at City 0, 1, 3, and 6, (3) stop only at City 0, 1, and 6. For HSR (Full Shinkansen) and Maglev, there can be an option to skip City 1, but we do not consider it because City 1 is the second most important city in the corridor. Note that the pattern of station skipping will apply to all high-speed trains. Also note that the skipping stations applies only to Full Shinkansen and Maglev, but not to the Incremental HSR, because the Incremental HSR shares the right-of-way with existing local trains. We assume that Incremental HSR trains stop all stations in all cases.

We make 9 different scenarios for analysis. (See Table 4-11)

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[*] Travel time includes dwell time (1 minute) at intermediate stations and transfer time (20 minutes) if necessary.

Table 4-11: Nine Scenarios (Three Operation Plan and Three Demand Patterns) in Region 2

	HSR (including Maglev) stops at all stations	**HSR (including Maglev) stops at only City 0, 1, 3, 6**	**HSR (including Maglev) stops at only City 0, 1, 6**
Demand is even; each O-D pair has the same amount of travel demand	Scenario #10	Scenario #11	Scenario #12
Demand between City 0, 1, 3, 6 are higher than those of other O-D pairs	Scenario #13	Scenario #14	Scenario #15
Demand between City 0, 1, 6 are higher than those of other O-D pairs	Scenario #16	Scenario #17	Scenario #18

The assumptions of travel demand for all origin-destination pair are summarized in the following table. Note that the total travel demand is set to 30,000 for each scenario.

Table 4-12: Daily OD-Demand for each Scenario (Daily, hundreds) in Region 2

City from	City to	Scenario #10	Scenario #11	Scenario #12	Scenario #13	Scenario #14	Scenario #15	Scenario #16	Scenario #17	Scenario #18
0	1	20	20	20	45	45	45	80	80	80
0	2	20	20	20	10	10	10	10	10	10
0	3	20	20	20	45	45	45	10	10	10
0	4	20	20	20	10	10	10	10	10	10
0	5	20	20	20	10	10	10	10	10	10
0	6	20	20	20	45	45	45	80	80	80
1	2	20	20	20	10	10	10	10	10	10
1	3	20	20	20	45	45	45	10	10	10
1	4	20	20	20	10	10	10	10	10	10
1	5	20	20	20	10	10	10	10	10	10
1	6	20	20	20	45	45	45	80	80	80
2	3	20	20	20	10	10	10	10	10	10
2	4	20	20	20	10	10	10	10	10	10
2	5	20	20	20	10	10	10	10	10	10
2	6	20	20	20	10	10	10	10	10	10
3	4	20	20	20	10	10	10	10	10	10
3	5	20	20	20	10	10	10	10	10	10
3	6	20	20	20	45	45	45	10	10	10
4	5	20	20	20	10	10	10	10	10	10
4	6	20	20	20	10	10	10	10	10	10
5	6	20	20	20	10	10	10	10	10	10
total demand		420	420	420	420	420	420	420	420	420

We analyzed the travel time savings for each scenario and summarized for each stations. The time savings shows the savings for one direction, although we define all passengers make return trip. Following is the result of scenario analyses. First, the time savings of nine scenarios are presented, and total time savings for the entire corridor and time savings for each station are analyzed.

Scenario #10: **OD demand is even.**
Every train stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	146	200	487
0	3	520	188	200	628
0	4	580	231	200	769
0	5	640	273	200	911
0	6	700	316	200	1052
1	2	60	41	200	138
1	3	120	84	200	279
1	4	180	126	200	421
1	5	240	169	200	562
1	6	300	211	200	703
2	3	60	41	200	138
2	4	120	84	200	279
2	5	180	126	200	421
2	6	240	169	200	562
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	126	200	421
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
			total passenger travel time (hours)		9024
			Passenger time savings (hours)		0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	131	200	436
0	3	520	158	200	528
0	4	580	186	200	619
0	5	640	213	200	710
0	6	700	240	200	801
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
			total passenger travel time (hours)		6512
			Passenger time savings (hours)		2512

(3) Mini Shinkansen (150 km/h)

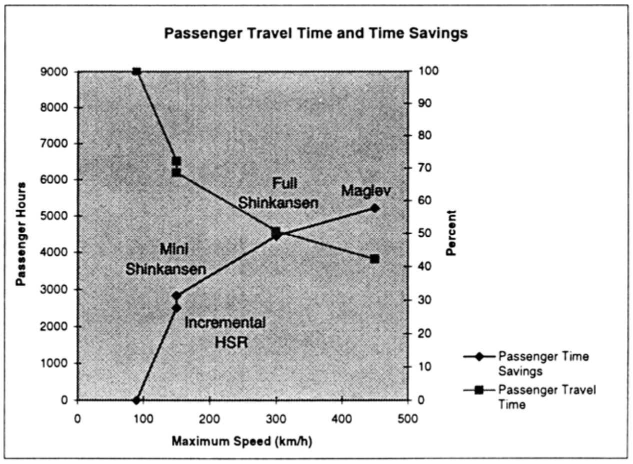
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	112	200	373
0	3	520	139	200	464
0	4	580	167	200	555
0	5	640	194	200	646
0	6	700	221	200	737
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
			total passenger travel time (hours)		6195
			Passenger time savings (hours)		2829

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	102	200	341
0	3	520	120	200	400
0	4	580	138	200	458
0	5	640	155	200	517
0	6	700	173	200	576
1	2	60	17	200	55
1	3	120	34	200	114
1	4	180	52	200	173
1	5	240	70	200	232
1	6	300	87	200	290
2	3	60	17	200	55
2	4	120	34	200	114
2	5	180	52	200	173
2	6	240	70	200	232
3	4	60	17	200	55
3	5	120	34	200	114
3	6	180	52	200	173
4	5	60	17	200	55
4	6	120	34	200	114
5	6	60	17	200	55
			total passenger travel time (hours)		4581
			Passenger time savings (hours)		4443

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	200	201
0	2	460	76	200	254
0	3	520	92	200	307
0	4	580	108	200	360
0	5	640	124	200	414
0	6	700	140	200	467
1	2	60	15	200	50
1	3	120	31	200	103
1	4	180	47	200	156
1	5	240	63	200	209
1	6	300	79	200	262
2	3	60	15	200	50
2	4	120	31	200	103
2	5	180	47	200	156
2	6	240	63	200	209
3	4	60	15	200	50
3	5	120	31	200	103
3	6	180	47	200	156
4	5	60	15	200	50
4	6	120	31	200	103
5	6	60	15	200	50
			total passenger travel time (hours)		3813
			Passenger time savings (hours)		5211



Scenario #11: OD demand is even.
Full Shinkansen and Maglev stop only at station 0,1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	146	200	487
0	3	520	188	200	628
0	4	580	231	200	769
0	5	640	273	200	911
0	6	700	316	200	1052
1	2	60	41	200	138
1	3	120	84	200	279
1	4	180	126	200	421
1	5	240	169	200	562
1	6	300	211	200	703
2	3	60	41	200	138
2	4	120	84	200	279
2	5	180	126	200	421
2	6	240	169	200	562
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	126	200	421
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
			total passenger travel time (hours)		9024
			Passenger time savings (hours)		0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	131	200	436
0	3	520	158	200	528
0	4	580	186	200	619
0	5	640	213	200	710
0	6	700	240	200	801
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
			total passenger travel time (hours)		6512
			Passenger time savings (hours)		2512

(3) Mini Shinkansen (150 km/h)

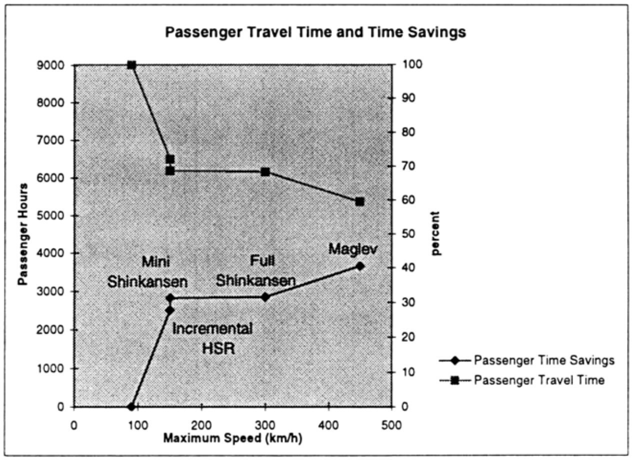
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	112	200	373
0	3	520	139	200	464
0	4	580	167	200	555
0	5	640	194	200	646
0	6	700	221	200	737
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
			total passenger travel time (hours)		6195
			Passenger time savings (hours)		2829

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	146	200	487
0	3	520	114	200	381
0	4	580	188	200	625
0	5	640	242	200	807
0	6	700	156	200	520
1	2	60	41	200	138
1	3	120	29	200	95
1	4	180	90	200	300
1	5	240	132	200	441
1	6	300	70	200	234
2	3	60	41	200	138
2	4	120	41	200	138
2	5	180	41	200	138
2	6	240	102	200	340
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	41	200	135
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
			total passenger travel time (hours)		6172
			Passenger time savings (hours)		2852

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	200	201
0	2	460	122	200	406
0	3	520	84	200	281
0	4	580	154	200	512
0	5	640	204	200	680
0	6	700	116	200	387
1	2	60	41	200	138
1	3	120	23	200	76
1	4	180	84	200	281
1	5	240	127	200	422
1	6	300	55	200	183
2	3	60	41	200	138
2	4	120	41	200	138
2	5	180	41	200	138
2	6	240	92	200	308
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	31	200	103
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
			total passenger travel time (hours)		5365
			Passenger time savings (hours)		3659



Scenario #12: OD demand is even.
Full Shinkansen and Maglev stop only at station 0,1,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	146	200	487
0	3	520	188	200	628
0	4	580	231	200	769
0	5	640	273	200	911
0	6	700	316	200	1052
1	2	60	41	200	138
1	3	120	84	200	279
1	4	180	126	200	421
1	5	240	169	200	562
1	6	300	211	200	703
2	3	60	41	200	138
2	4	120	84	200	279
2	5	180	126	200	421
2	6	240	169	200	562
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	126	200	421
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
				total passenger travel time (hours)	9024
				Passenger time savings (hours)	0

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	146	200	487
0	3	520	188	200	628
0	4	580	231	200	769
0	5	640	273	200	911
0	6	700	150	200	501
1	2	60	41	200	138
1	3	120	84	200	279
1	4	180	126	200	421
1	5	240	169	200	562
1	6	300	65	200	215
2	3	60	41	200	138
2	4	120	84	200	279
2	5	180	126	200	421
2	6	240	169	200	562
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	126	200	421
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
				total passenger travel time (hours)	7985
				Passenger time savings (hours)	1039

(2) Incremental HSR (150 km/h)

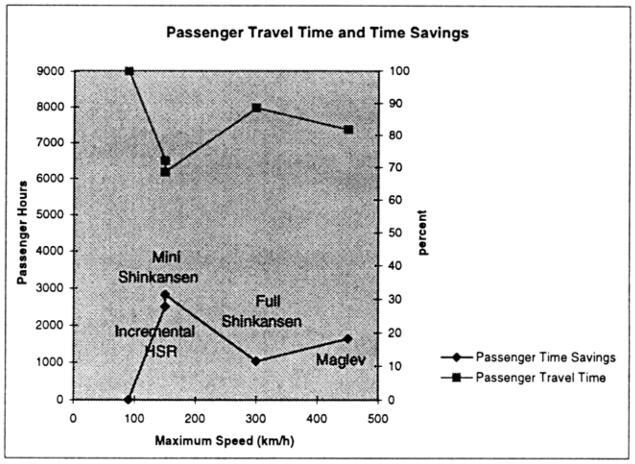
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	131	200	436
0	3	520	158	200	528
0	4	580	186	200	619
0	5	640	213	200	710
0	6	700	240	200	801
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
				total passenger travel time (hours)	6512
				Passenger time savings (hours)	2512

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	200	201
0	2	460	122	200	406
0	3	520	164	200	547
0	4	580	206	200	688
0	5	640	249	200	829
0	6	700	108	200	361
1	2	60	41	200	138
1	3	120	84	200	279
1	4	180	126	200	421
1	5	240	169	200	562
1	6	300	47	200	156
2	3	60	41	200	138
2	4	120	84	200	279
2	5	180	126	200	421
2	6	240	169	200	562
3	4	60	41	200	138
3	5	120	84	200	279
3	6	180	126	200	421
4	5	60	41	200	138
4	6	120	84	200	279
5	6	60	41	200	138
				total passenger travel time (hours)	7380
				Passenger time savings (hours)	1644

(3) Mini Shinkansen (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	200	282
0	2	460	112	200	373
0	3	520	139	200	464
0	4	580	167	200	555
0	5	640	194	200	646
0	6	700	221	200	737
1	2	60	26	200	88
1	3	120	54	200	179
1	4	180	81	200	270
1	5	240	108	200	361
1	6	300	136	200	452
2	3	60	26	200	88
2	4	120	54	200	179
2	5	180	81	200	270
2	6	240	108	200	361
3	4	60	26	200	88
3	5	120	54	200	179
3	6	180	81	200	270
4	5	60	26	200	88
4	6	120	54	200	179
5	6	60	26	200	88
				total passenger travel time (hours)	6195
				Passenger time savings (hours)	2829



Scenario #13: **OD demand is higher among city 0,1,3,6.**
Every train stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	146	100	243
0	3	520	188	450	1413
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	450	2367
1	2	60	41	100	69
1	3	120	84	450	628
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	450	1582
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	450	946
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
				total passenger travel time (hours)	10401
				Passenger time savings (hours)	0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	131	100	218
0	3	520	158	450	1187
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	450	1802
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
				total passenger travel time (hours)	7650
				Passenger time savings (hours)	2751

(3) Mini Shinkansen (150 km/h)

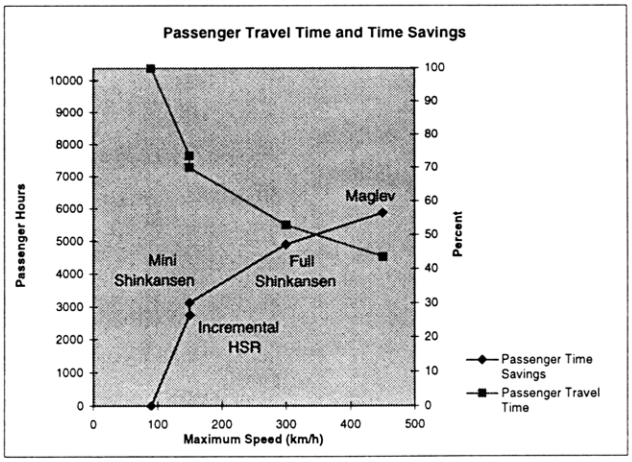
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	112	100	187
0	3	520	139	450	1044
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	450	1659
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
				total passenger travel time (hours)	7270
				Passenger time savings (hours)	3131

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	102	100	170
0	3	520	120	450	899
0	4	580	138	100	229
0	5	640	155	100	259
0	6	700	173	450	1296
1	2	60	17	100	28
1	3	120	34	450	257
1	4	180	52	100	86
1	5	240	70	100	116
1	6	300	87	450	654
2	3	60	17	100	28
2	4	120	34	100	57
2	5	180	52	100	86
2	6	240	70	100	116
3	4	60	17	100	28
3	5	120	34	100	57
3	6	180	52	450	389
4	5	60	17	100	28
4	6	120	34	100	57
5	6	60	17	100	28
				total passenger travel time (hours)	5502
				Passenger time savings (hours)	4899

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	450	452
0	2	460	76	100	127
0	3	520	92	450	691
0	4	580	108	100	180
0	5	640	124	100	207
0	6	700	140	450	1050
1	2	60	15	100	25
1	3	120	31	450	232
1	4	180	47	100	78
1	5	240	63	100	105
1	6	300	79	450	590
2	3	60	15	100	25
2	4	120	31	100	51
2	5	180	47	100	78
2	6	240	63	100	105
3	4	60	15	100	25
3	5	120	31	100	51
3	6	180	47	450	351
4	5	60	15	100	25
4	6	120	31	100	51
5	6	60	15	100	25
				total passenger travel time (hours)	4525
				Passenger time savings (hours)	5876



Scenario #14: **OD demand is higher among city 0,1,3,6.**
Full Shinkansen and Maglev stop only at station 0,1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	146	100	243
0	3	520	188	450	1413
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	450	2367
1	2	60	41	100	69
1	3	120	84	450	628
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	450	1582
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	450	946
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		10401
			Passenger time savings (hours)		0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	131	100	218
0	3	520	158	450	1187
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	450	1802
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
			total passenger travel time (hours)		7650
			Passenger time savings (hours)		2751

(3) Mini Shinkansen (150 km/h)

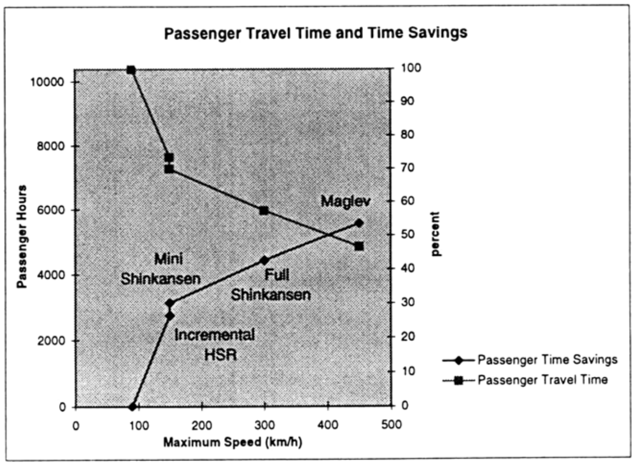
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	112	100	187
0	3	520	139	450	1044
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	450	1659
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
			total passenger travel time (hours)		7270
			Passenger time savings (hours)		3131

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	146	100	243
0	3	520	114	450	857
0	4	580	188	100	313
0	5	640	242	100	403
0	6	700	156	450	1169
1	2	60	41	100	69
1	3	120	29	450	215
1	4	180	90	100	150
1	5	240	132	100	221
1	6	300	70	450	527
2	3	60	41	100	69
2	4	120	41	100	69
2	5	180	41	100	69
2	6	240	102	100	170
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	41	450	305
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		5970
			Passenger time savings (hours)		4431

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	450	452
0	2	460	122	100	203
0	3	520	84	450	632
0	4	580	154	100	256
0	5	640	204	100	340
0	6	700	116	450	871
1	2	60	41	100	69
1	3	120	23	450	172
1	4	180	84	100	141
1	5	240	127	100	211
1	6	300	55	450	412
2	3	60	41	100	69
2	4	120	41	100	69
2	5	180	41	100	69
2	6	240	92	100	154
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	31	450	232
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		4837
			Passenger time savings (hours)		5563



Scenario #15: OD demand is higher among city 0,1,3,6.
Full Shinkansen and Maglev stop only at station 0,1,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	146	100	243
0	3	520	188	450	1413
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	450	2367
1	2	60	41	100	69
1	3	120	84	450	628
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	450	1582
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	450	946
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 10401
Passenger time savings (hours) 0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	131	100	218
0	3	520	158	450	1187
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	450	1802
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44

total passenger travel time (hours) 7650
Passenger time savings (hours) 2751

(3) Mini Shinkansen (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	112	100	187
0	3	520	139	450	1044
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	450	1659
1	2	60	26	100	44
1	3	120	54	450	402
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	450	1017
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	450	607
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44

total passenger travel time (hours) 7270
Passenger time savings (hours) 3131

(4) Full Shinkansen (300 km/h

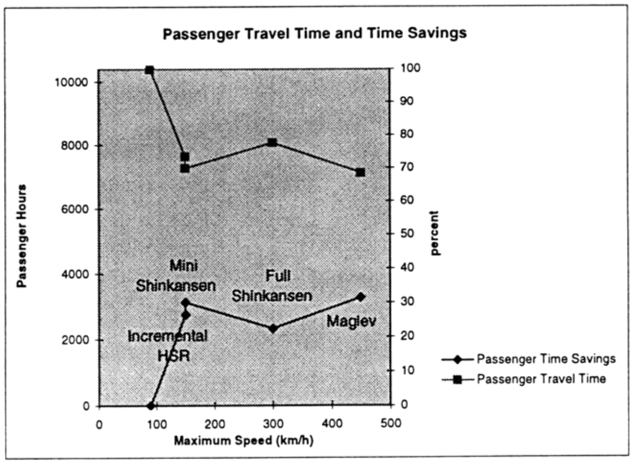
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	450	635
0	2	460	146	100	243
0	3	520	188	450	1413
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	150	450	1127
1	2	60	41	100	69
1	3	120	84	450	628
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	65	450	485
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	450	946
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 8064
Passenger time savings (hours) 2337

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	450	452
0	2	460	122	100	203
0	3	520	164	450	1230
0	4	580	206	100	344
0	5	640	249	100	415
0	6	700	108	450	812
1	2	60	41	100	69
1	3	120	84	450	628
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	47	450	352
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	450	946
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 7129
Passenger time savings (hours) 3272



Scenario #16: **OD demand is higher among city 0,1,6.**
Every train stops all stations.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	146	100	243
0	3	520	188	100	314
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	800	4208
1	2	60	41	100	69
1	3	120	84	100	140
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	800	2813
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	100	210
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
				total passenger travel time (hours)	11642
				Passenger time savings (hours)	0

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	102	100	170
0	3	520	120	100	200
0	4	580	138	100	229
0	5	640	155	100	259
0	6	700	173	800	2304
1	2	60	17	100	28
1	3	120	34	100	57
1	4	180	52	100	86
1	5	240	70	100	116
1	6	300	87	800	1162
2	3	60	17	100	28
2	4	120	34	100	57
2	5	180	52	100	86
2	6	240	70	100	116
3	4	60	17	100	28
3	5	120	34	100	57
3	6	180	52	100	86
4	5	60	17	100	28
4	6	120	34	100	57
5	6	60	17	100	28
				total passenger travel time (hours)	6310
				Passenger time savings (hours)	5332

(2) Incremental HSR (150 km/h)

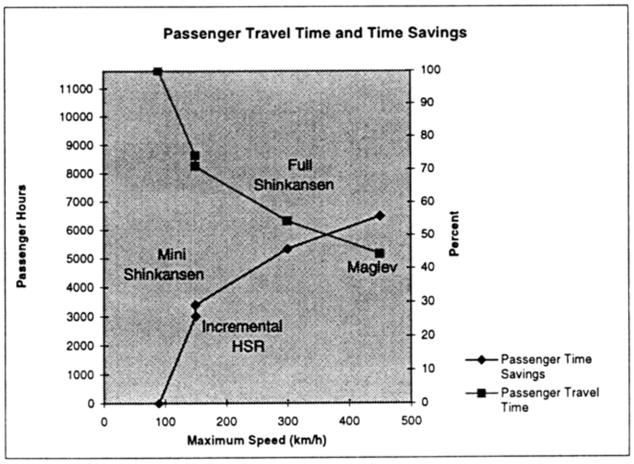
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	131	100	218
0	3	520	158	100	264
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	800	3203
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
				total passenger travel time (hours)	8627
				Passenger time savings (hours)	3015

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	800	804
0	2	460	76	100	127
0	3	520	92	100	154
0	4	580	108	100	180
0	5	640	124	100	207
0	6	700	140	800	1867
1	2	60	15	100	25
1	3	120	31	100	51
1	4	180	47	100	78
1	5	240	63	100	105
1	6	300	79	800	1050
2	3	60	15	100	25
2	4	120	31	100	51
2	5	180	47	100	78
2	6	240	63	100	105
3	4	60	15	100	25
3	5	120	31	100	51
3	6	180	47	100	78
4	5	60	15	100	25
4	6	120	31	100	51
5	6	60	15	100	25
				total passenger travel time (hours)	5161
				Passenger time savings (hours)	6481

(3) Mini Shinkansen (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	112	100	187
0	3	520	139	100	232
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	800	2949
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
				total passenger travel time (hours)	8247
				Passenger time savings (hours)	3395



Scenario #17: OD demand is higher among city 0,1,6.
Full Shinkansen and Maglev stop only at station 0,1,3,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	146	100	243
0	3	520	188	100	314
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	800	4208
1	2	60	41	100	69
1	3	120	84	100	140
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	800	2813
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	100	210
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		11642
			Passenger time savings (hours)		0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	131	100	218
0	3	520	158	100	264
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	800	3203
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
			total passenger travel time (hours)		8627
			Passenger time savings (hours)		3015

(3) Mini Shinkansen (150 km/h)

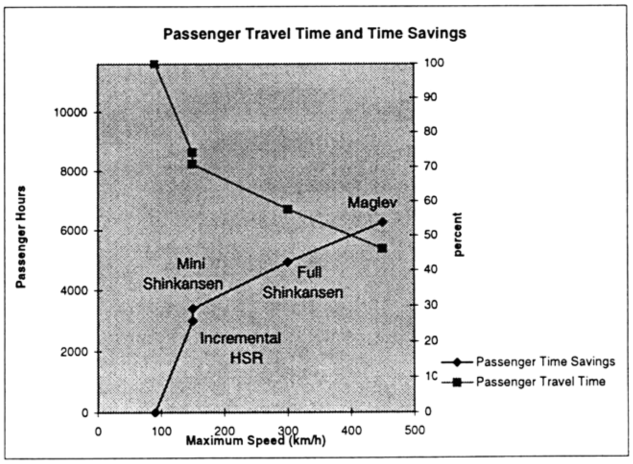
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	112	100	187
0	3	520	139	100	232
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	800	2949
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44
			total passenger travel time (hours)		8247
			Passenger time savings (hours)		3395

(4) Full Shinkansen (300 km/h

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	146	100	243
0	3	520	114	100	190
0	4	580	188	100	313
0	5	640	242	100	403
0	6	700	156	800	2079
1	2	60	41	100	69
1	3	120	29	100	48
1	4	180	90	100	150
1	5	240	132	100	221
1	6	300	70	800	937
2	3	60	41	100	69
2	4	120	41	100	69
2	5	180	41	100	69
2	6	240	102	100	170
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	41	100	68
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		6712
			Passenger time savings (hours)		4930

(5) Maglev (450 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	800	804
0	2	460	122	100	203
0	3	520	84	100	140
0	4	580	154	100	256
0	5	640	204	100	340
0	6	700	116	800	1549
1	2	60	41	100	69
1	3	120	23	100	38
1	4	180	84	100	141
1	5	240	127	100	211
1	6	300	55	800	732
2	3	60	41	100	69
2	4	120	41	100	69
2	5	180	41	100	69
2	6	240	92	100	154
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	31	100	52
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69
			total passenger travel time (hours)		5381
			Passenger time savings (hours)		6261



Scenario #18: **OD demand is higher among city 0,1,6.**
Full Shinkansen and Maglev stop only at station 0,1,6.

(1) Status quo (Max Speed: 90 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	146	100	243
0	3	520	188	100	314
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	316	800	4208
1	2	60	41	100	69
1	3	120	84	100	140
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	211	800	2813
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	100	210
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 11642
Passenger time savings (hours) 0

(2) Incremental HSR (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	131	100	218
0	3	520	158	100	264
0	4	580	186	100	309
0	5	640	213	100	355
0	6	700	240	800	3203
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44

total passenger travel time (hours) 8627
Passenger time savings (hours) 3015

(3) Mini Shinkansen (150 km/h)

city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	112	100	187
0	3	520	139	100	232
0	4	580	167	100	278
0	5	640	194	100	323
0	6	700	221	800	2949
1	2	60	26	100	44
1	3	120	54	100	89
1	4	180	81	100	135
1	5	240	108	100	180
1	6	300	136	800	1808
2	3	60	26	100	44
2	4	120	54	100	89
2	5	180	81	100	135
2	6	240	108	100	180
3	4	60	26	100	44
3	5	120	54	100	89
3	6	180	81	100	135
4	5	60	26	100	44
4	6	120	54	100	89
5	6	60	26	100	44

total passenger travel time (hours) 8247
Passenger time savings (hours) 3395

(4) Full Shinkansen (300 km/h

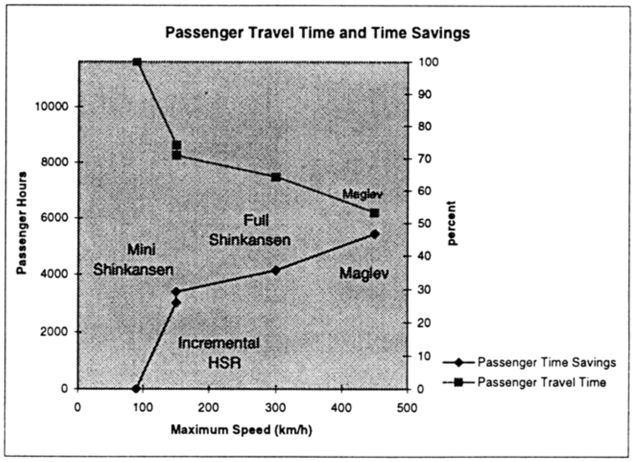
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	85	800	1128
0	2	460	146	100	243
0	3	520	188	100	314
0	4	580	231	100	385
0	5	640	273	100	455
0	6	700	150	800	2003
1	2	60	41	100	69
1	3	120	84	100	140
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	65	800	862
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	100	210
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 7487
Passenger time savings (hours) 4155

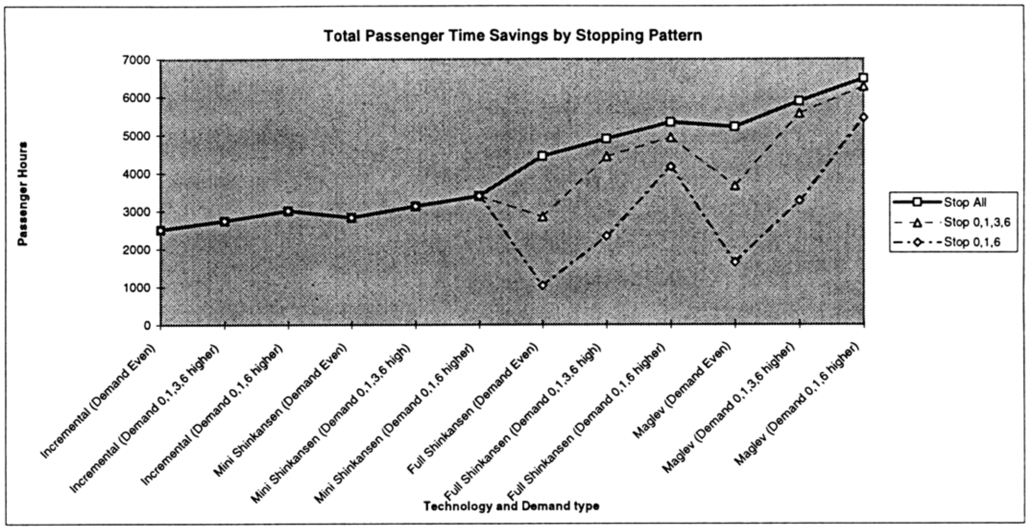
(5) Maglev (450 km/h)

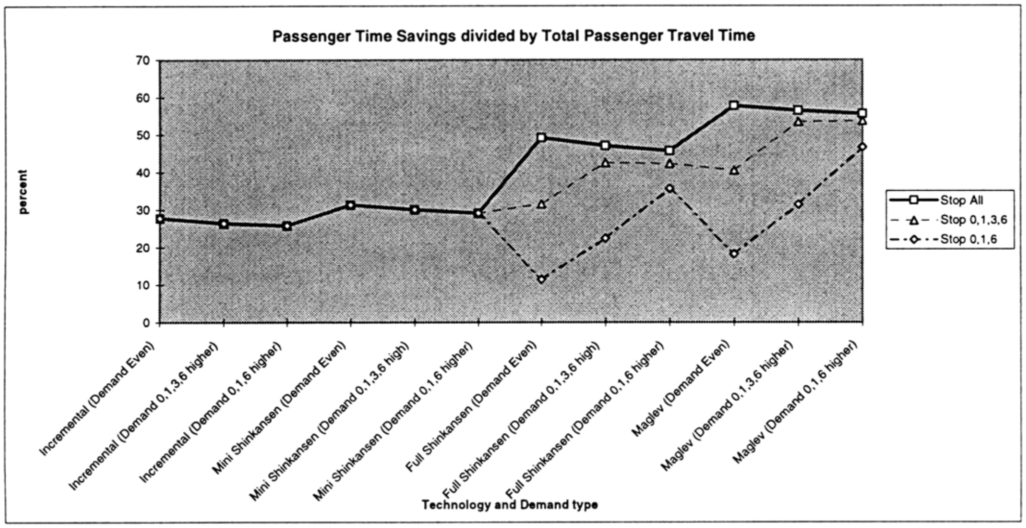
city from	city to	distance (km)	travel time (minutes)	daily pass. demand	passenger travel time
0	1	400	60	800	804
0	2	460	122	100	203
0	3	520	164	100	273
0	4	580	206	100	344
0	5	640	249	100	415
0	6	700	108	800	1443
1	2	60	41	100	69
1	3	120	84	100	140
1	4	180	126	100	210
1	5	240	169	100	281
1	6	300	47	800	626
2	3	60	41	100	69
2	4	120	84	100	140
2	5	180	126	100	210
2	6	240	169	100	281
3	4	60	41	100	69
3	5	120	84	100	140
3	6	180	126	100	210
4	5	60	41	100	69
4	6	120	84	100	140
5	6	60	41	100	69

total passenger travel time (hours) 6204
Passenger time savings (hours) 5438



Total Passenger Time Savings by Stopping Pattern

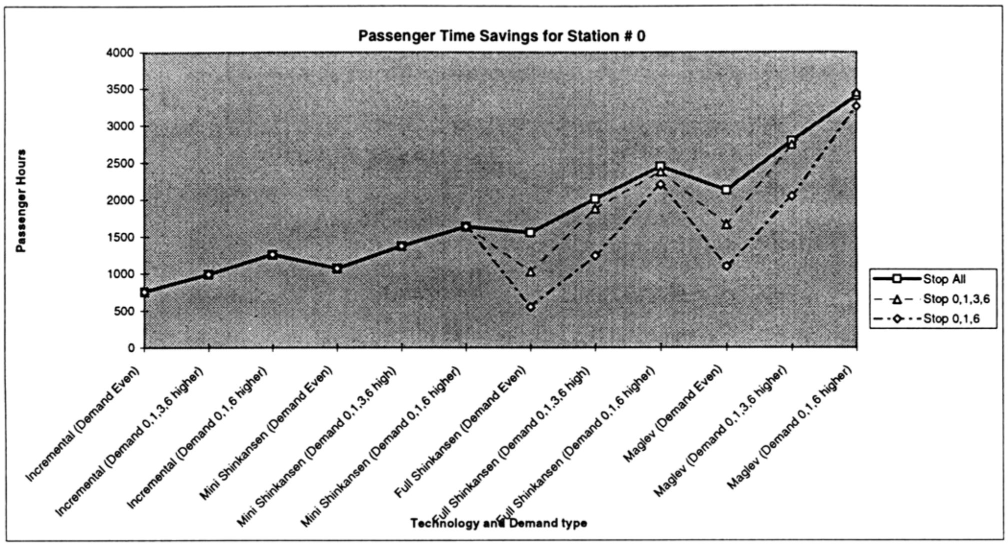


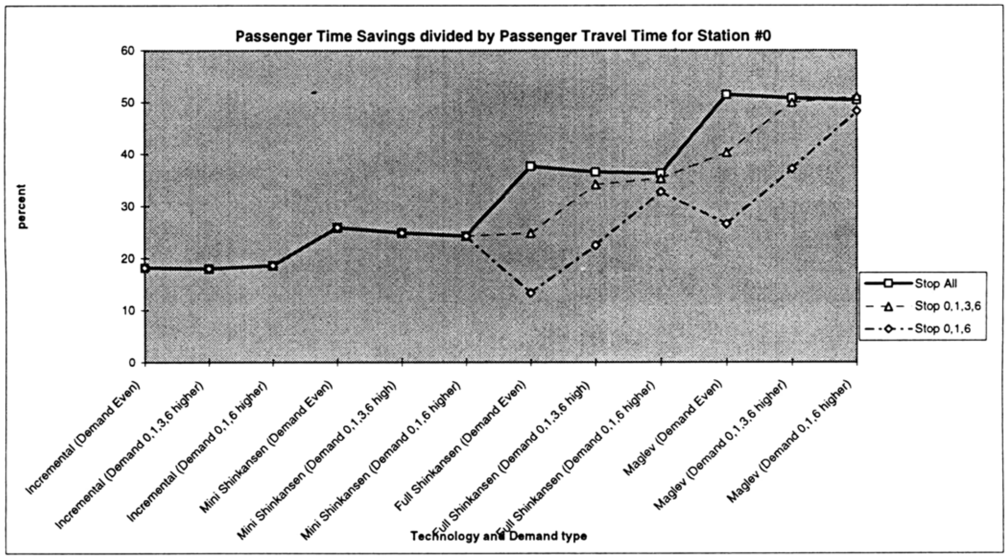


Total Passenger Travel Time (Status quo)	hour
Demand Even	9024
Demand 1,3,6 higher	10401
Demand 1,6 higher	11642

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	2512	27.84	2512	27.84	2512	27.84
Incremental (Demand 0,1,3,6 higher)	2751	26.45	2751	26.45	2751	26.45
Incremental (Demand 0,1,6 higher)	3015	25.90	3015	25.90	3015	25.90
Mini Shinkansen (Demand Even)	2829	31.35	2829	31.35	2829	31.35
Mini Shinkansen (Demand 0,1,3,6 high)	3131	30.10	3131	30.10	3131	30.10
Mini Shinkansen (Demand 0,1,6 higher)	3395	29.16	3395	29.16	3395	29.16
Full Shinkansen (Demand Even)	4443	49.24	2852	31.60	1039	11.51
Full Shinkansen (Demand 0,1,3,6 high)	4899	47.10	4431	42.60	2337	22.47
Full Shinkansen (Demand 0,1,6 higher)	5332	45.80	4930	42.35	4155	35.69
Maglev (Demand Even)	5211	57.75	3659	40.55	1644	18.21
Maglev (Demand 0,1,3,6 higher)	5876	56.49	5563	53.49	3272	31.46
Maglev (Demand 0,1,6 higher)	6481	55.67	6261	53.78	5438	46.71

Station #0

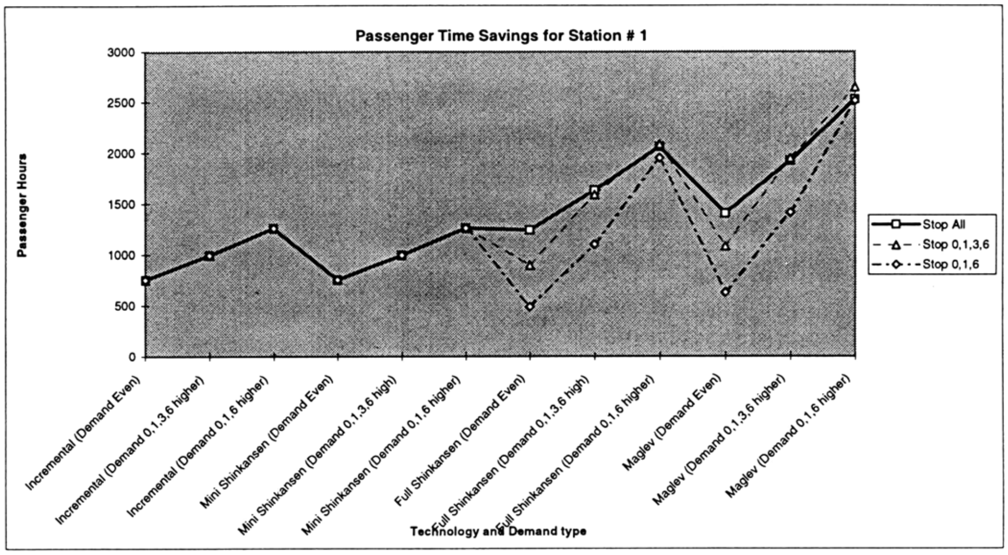

Passenger Time Savings for Station # 0

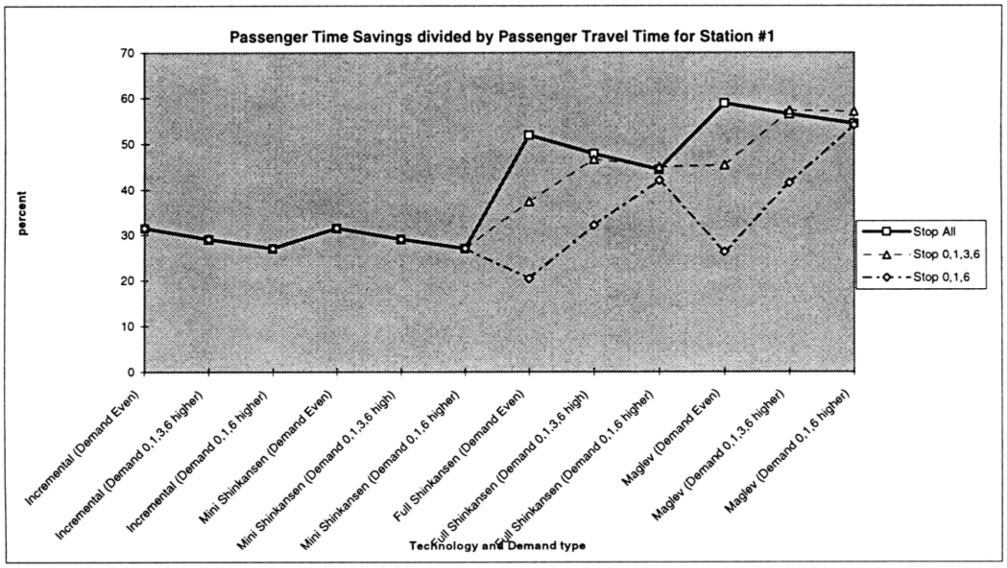

Passenger Time Savings divided by Passenger Travel Time for Station #0

Total Passenger Travel Time (Status quo)	hour
Demand Even	4129
Demand 1,3,6 higher	5498
Demand 1,6 higher	6733

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	754	18.26	754	18.26	754	18.26
Incremental (Demand 0,1,3,6 higher)	992	18.05	992	18.05	992	18.05
Incremental (Demand 0,1,6 higher)	1256	18.66	1256	18.66	1256	18.66
Mini Shinkansen (Demand Even)	1070	25.93	1070	25.93	1070	25.93
Mini Shinkansen (Demand 0,1,3,6 high)	1372	24.96	1372	24.96	1372	24.96
Mini Shinkansen (Demand 0,1,6 higher)	1636	24.30	1636	24.30	1636	24.30
Full Shinkansen (Demand Even)	1555	37.65	1027	24.88	551	13.35
Full Shinkansen (Demand 0,1,3,6 high)	2010	36.56	1878	34.15	1240	22.55
Full Shinkansen (Demand 0,1,6 higher)	2443	36.29	2377	35.29	2204	32.74
Maglev (Demand Even)	2126	51.49	1662	40.26	1097	26.57
Maglev (Demand 0,1,3,6 higher)	2791	50.76	2744	49.91	2042	37.14
Maglev (Demand 0,1,6 higher)	3395	50.43	3442	51.11	3252	48.29

Station #1

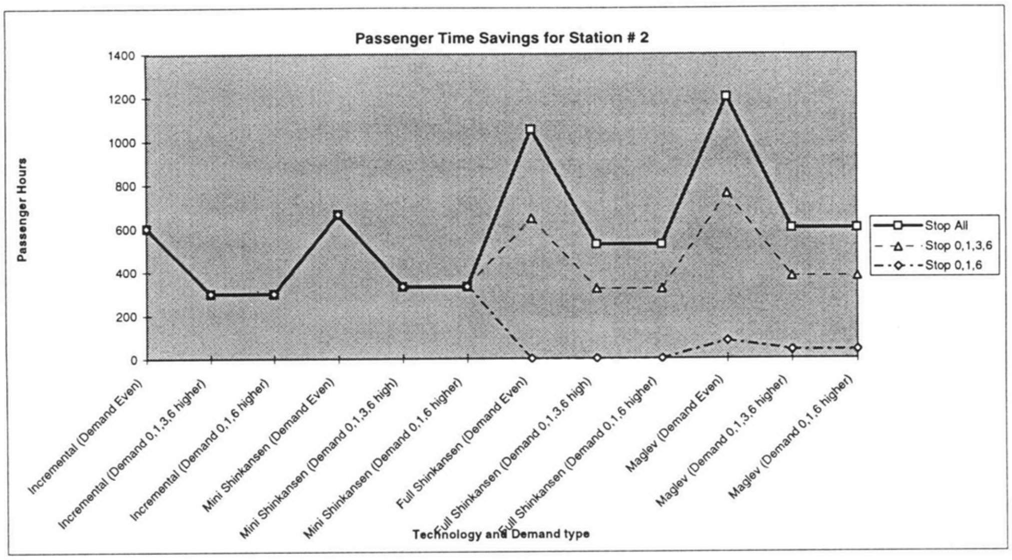


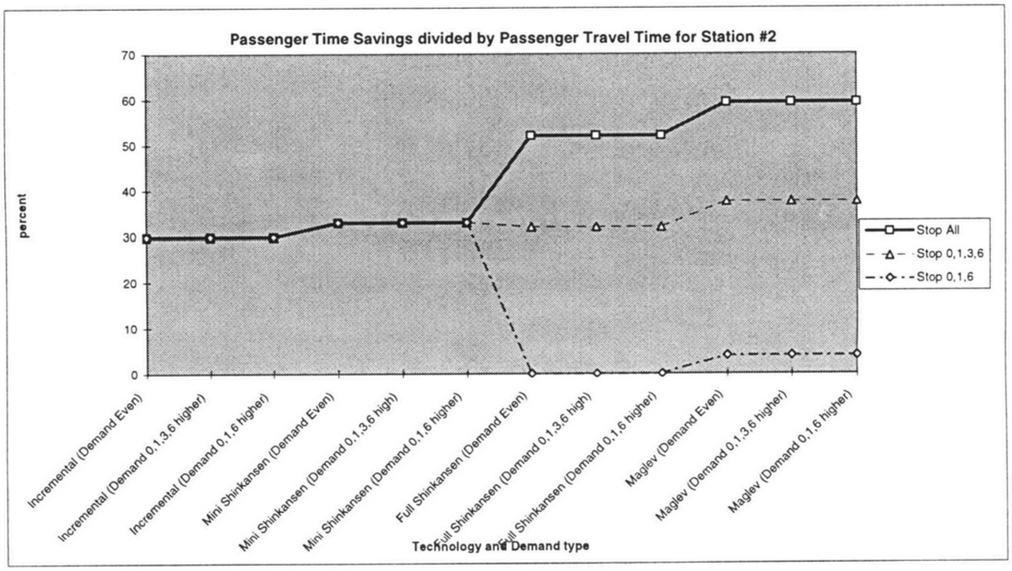


Total Passenger Travel Time (Status quo)	hour
Demand Even	2385
Demand 1,3,6 higher	3405
Demand 1,6 higher	4641

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	754	31.60	754	31.60	754	31.60
Incremental (Demand 0,1,3,6 higher)	992	29.14	992	29.14	992	29.14
Incremental (Demand 0,1,6 higher)	1256	27.07	1256	27.07	1256	27.07
Mini Shinkansen (Demand Even)	754	31.60	754	31.60	754	31.60
Mini Shinkansen (Demand 0,1,3,6 high)	992	29.14	992	29.14	992	29.14
Mini Shinkansen (Demand 0,1,6 higher)	1256	27.07	1256	27.07	1256	27.07
Full Shinkansen (Demand Even)	1238	51.91	894	37.48	488	20.45
Full Shinkansen (Demand 0,1,3,6 high)	1630	47.87	1589	46.67	1097	32.22
Full Shinkansen (Demand 0,1,6 higher)	2063	44.46	2088	45.00	1951	42.04
Maglev (Demand Even)	1403	58.85	1083	45.41	628	26.33
Maglev (Demand 0,1,3,6 higher)	1924	56.49	1949	57.23	1413	41.48
Maglev (Demand 0,1,6 higher)	2528	54.48	2646	57.02	2511	54.11

Station #2

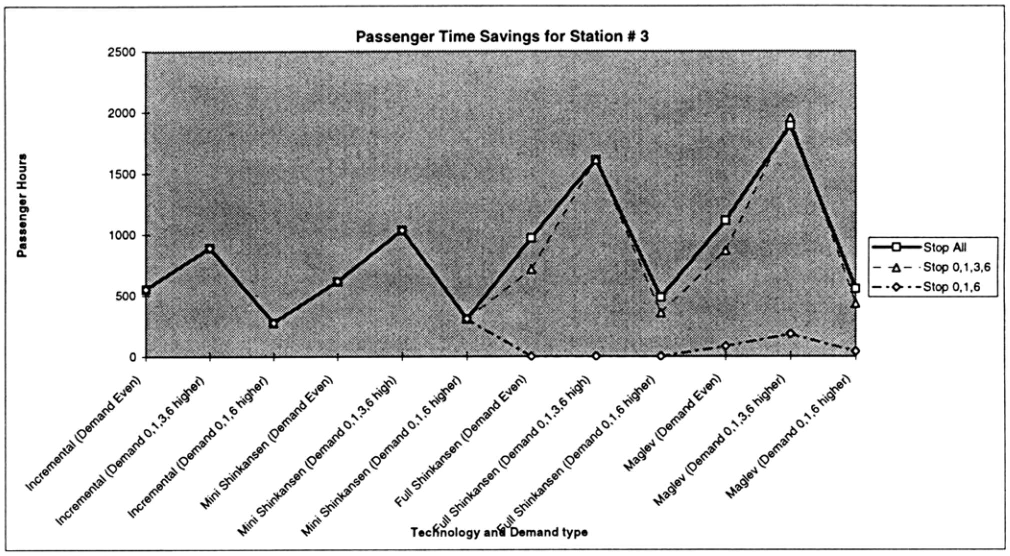


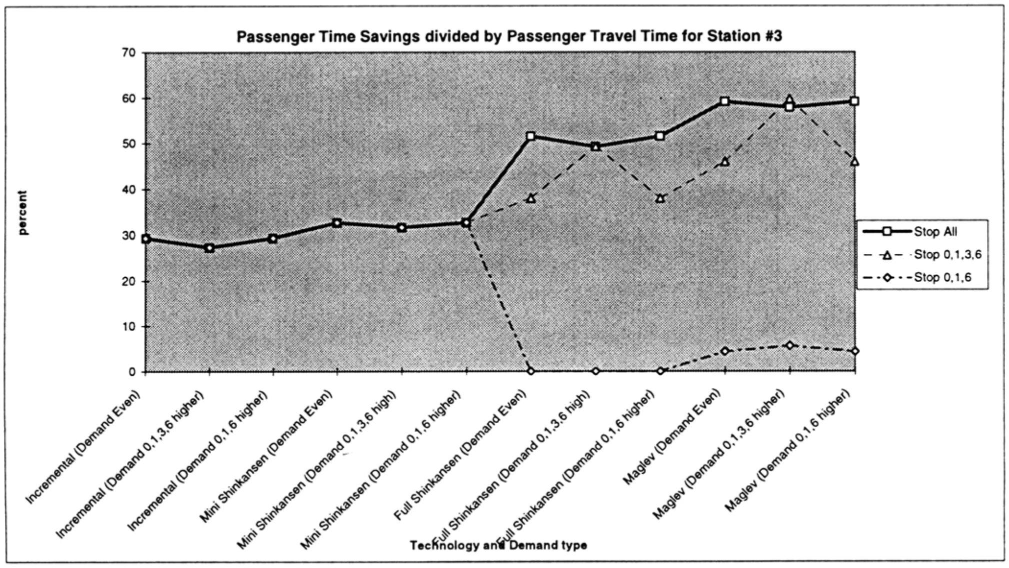


Total Passenger Travel Time (Status quo)	hour
Demand Even	2024
Demand 1,3,6 higher	1012
Demand 1,6 higher	1012

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	603	29.79	603	29.79	603	29.79
Incremental (Demand 0,1,3,6 higher)	301	29.79	301	29.79	301	29.79
Incremental (Demand 0,1,6 higher)	301	29.79	301	29.79	301	29.79
Mini Shinkansen (Demand Even)	666	32.91	666	32.91	666	32.91
Mini Shinkansen (Demand 0,1,3,6 high)	333	32.91	333	32.91	333	32.91
Mini Shinkansen (Demand 0,1,6 higher)	333	32.91	333	32.91	333	32.91
Full Shinkansen (Demand Even)	1054	52.05	646	31.90	0	0.00
Full Shinkansen (Demand 0,1,3,6 high)	527	52.05	323	31.90	0	0.00
Full Shinkansen (Demand 0,1,6 higher)	527	52.05	323	31.90	0	0.00
Maglev (Demand Even)	1202	59.39	759	37.50	81	4.01
Maglev (Demand 0,1,3,6 higher)	601	59.39	380	37.50	41	4.01
Maglev (Demand 0,1,6 higher)	601	59.39	380	37.50	41	4.01

Station #3

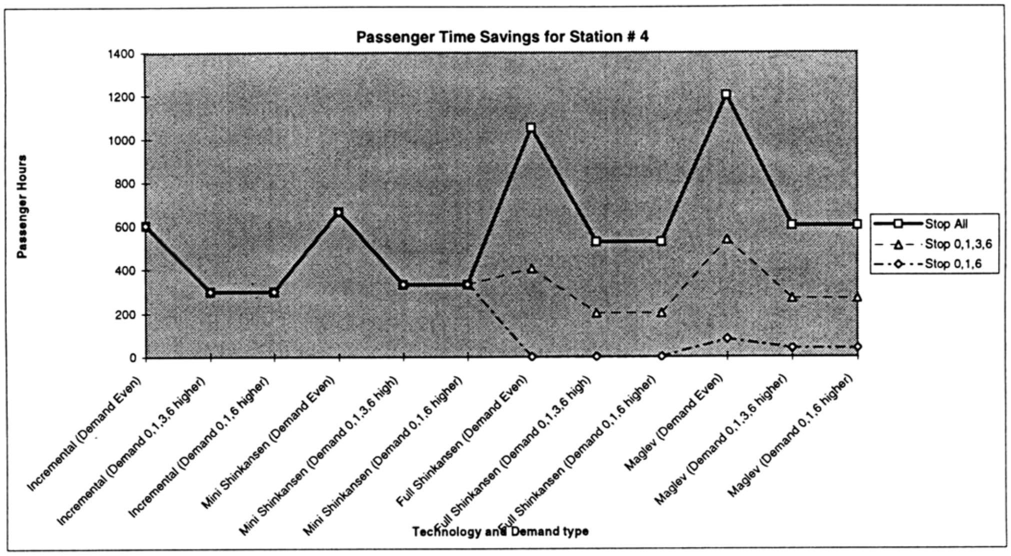


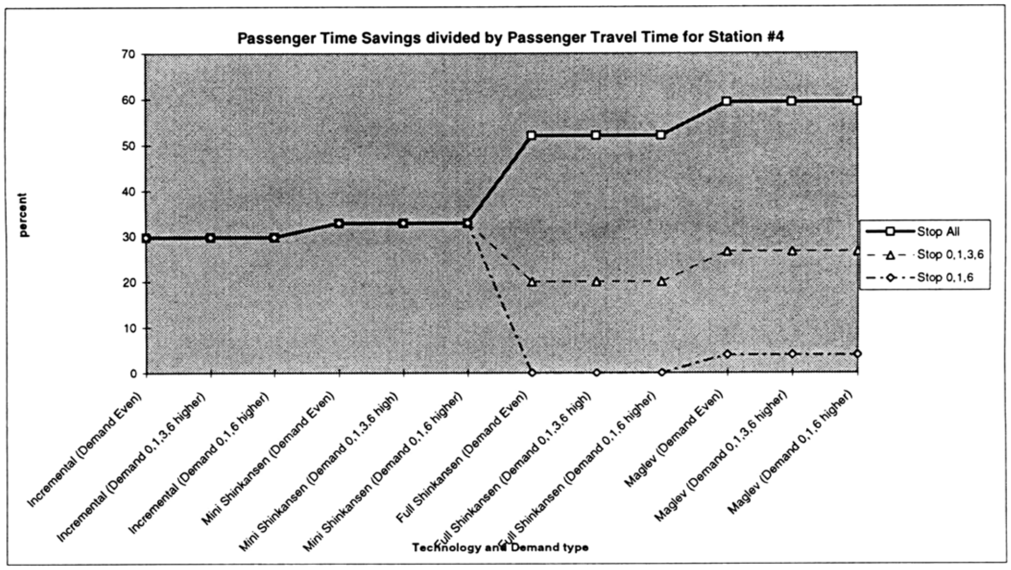


Total Passenger Travel Time (Status quo)	hour
Demand Even	1883
Demand 1,3,6 higher	3265
Demand 1,6 higher	942

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	553	29.35	553	29.35	553	29.35
Incremental (Demand 0,1,3,6 higher)	892	27.31	892	27.31	892	27.31
Incremental (Demand 0,1,6 higher)	276	29.35	276	29.35	276	29.35
Mini Shinkansen (Demand Even)	616	32.72	616	32.72	616	32.72
Mini Shinkansen (Demand 0,1,3,6 high)	1034	31.68	1034	31.68	1034	31.68
Mini Shinkansen (Demand 0,1,6 higher)	308	32.72	308	32.72	308	32.72
Full Shinkansen (Demand Even)	971	51.58	716	38.03	0	0.00
Full Shinkansen (Demand 0,1,3,6 high)	1607	49.23	1611	49.35	0	0.00
Full Shinkansen (Demand 0,1,6 higher)	486	51.58	358	38.03	0	0.00
Maglev (Demand Even)	1114	59.17	867	46.07	81	4.31
Maglev (Demand 0,1,3,6 higher)	1890	57.88	1952	59.78	183	5.59
Maglev (Demand 0,1,6 higher)	557	59.17	434	46.07	41	4.31

Station #4

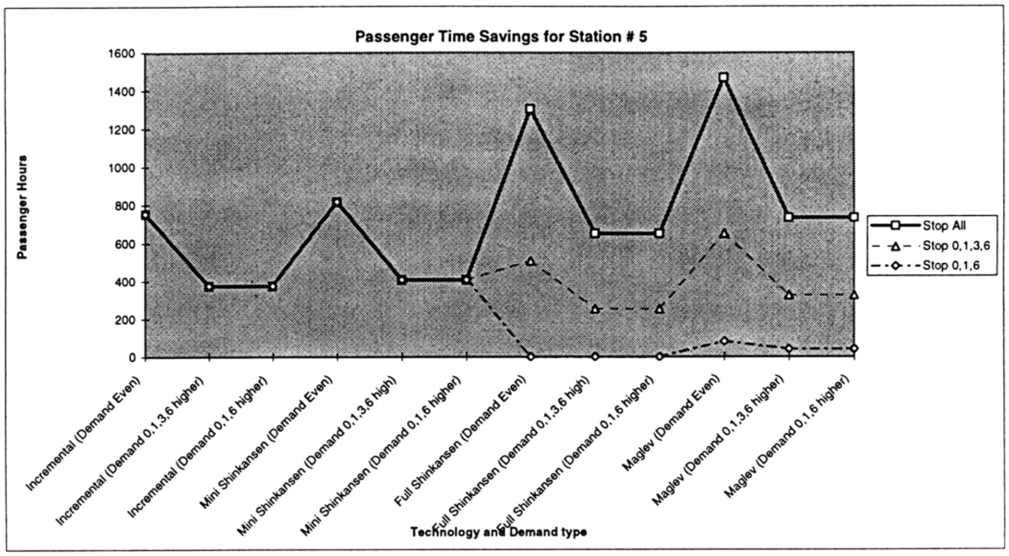


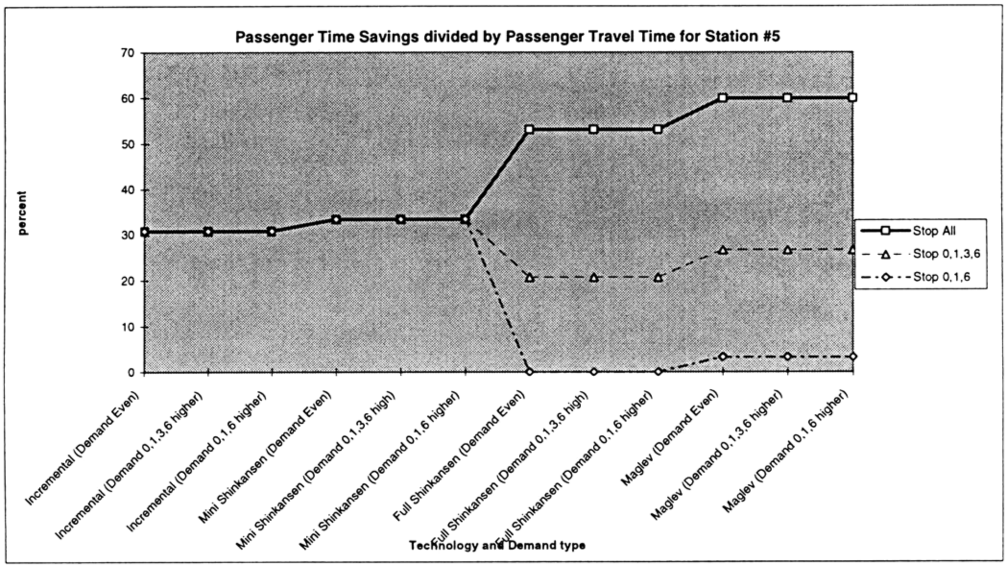


Total Passenger Travel Time (Status quo)	hour
Demand Even	2024
Demand 1,3,6 higher	1012
Demand 1,6 higher	1012

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	603	29.79	603	29.79	603	29.79
Incremental (Demand 0,1,3,6 higher)	301	29.79	301	29.79	301	29.79
Incremental (Demand 0,1,6 higher)	301	29.79	301	29.79	301	29.79
Mini Shinkansen (Demand Even)	666	32.91	666	32.91	666	32.91
Mini Shinkansen (Demand 0,1,3,6 high)	333	32.91	333	32.91	333	32.91
Mini Shinkansen (Demand 0,1,6 higher)	333	32.91	333	32.91	333	32.91
Full Shinkansen (Demand Even)	1054	52.05	406	20.04	0	0.00
Full Shinkansen (Demand 0,1,3,6 high)	527	52.05	203	20.04	0	0.00
Full Shinkansen (Demand 0,1,6 higher)	527	52.05	203	20.04	0	0.00
Maglev (Demand Even)	1202	59.39	538	26.58	81	4.01
Maglev (Demand 0,1,3,6 higher)	601	59.39	269	26.58	41	4.01
Maglev (Demand 0,1,6 higher)	601	59.39	269	26.58	41	4.01

Station #5

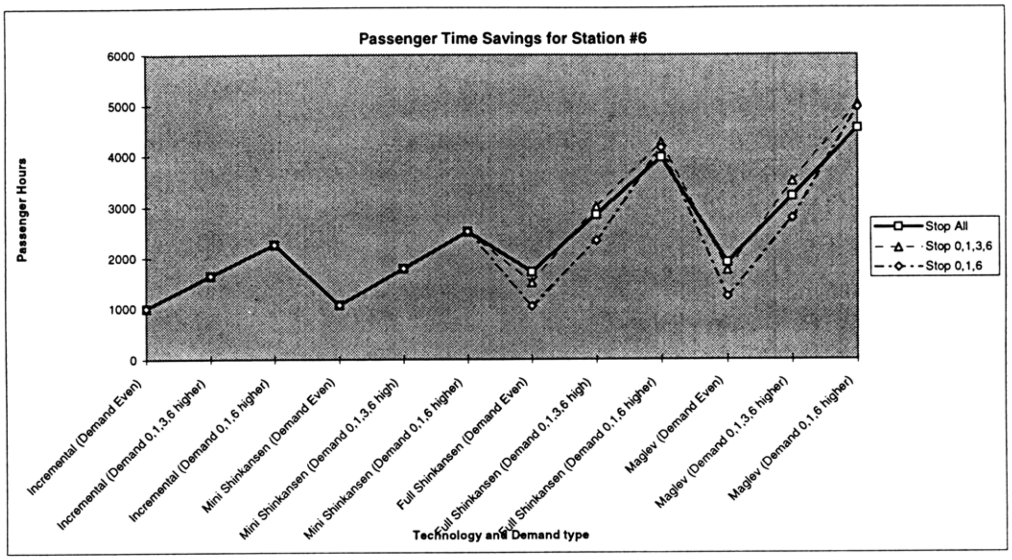


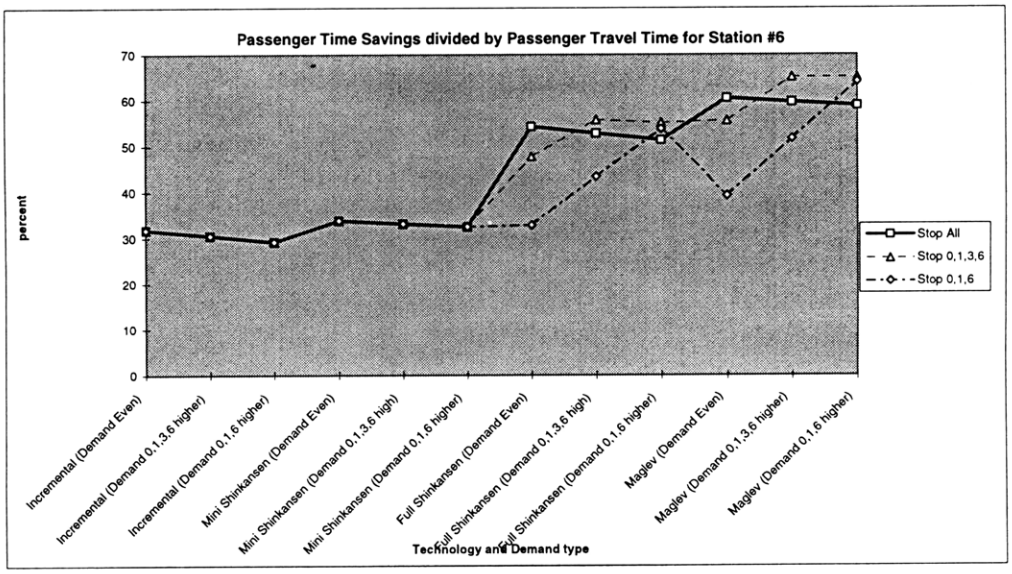


Total Passenger Travel Time (Status quo)	hour
Demand Even	2448
Demand 1,3,6 higher	1224
Demand 1,6 higher	1224

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	754	30.79	754	30.79	754	30.79
Incremental (Demand 0,1,3,6 higher)	377	30.79	377	30.79	377	30.79
Incremental (Demand 0,1,6 higher)	377	30.79	377	30.79	377	30.79
Mini Shinkansen (Demand Even)	817	33.37	817	33.37	817	33.37
Mini Shinkansen (Demand 0,1,3,6 high)	409	33.37	409	33.37	409	33.37
Mini Shinkansen (Demand 0,1,6 higher)	409	33.37	409	33.37	409	33.37
Full Shinkansen (Demand Even)	1301	53.15	507	20.71	0	0.00
Full Shinkansen (Demand 0,1,3,6 high)	651	53.15	253	20.71	0	0.00
Full Shinkansen (Demand 0,1,6 higher)	651	53.15	253	20.71	0	0.00
Maglev (Demand Even)	1467	59.91	653	26.66	81	3.32
Maglev (Demand 0,1,3,6 higher)	733	59.91	326	26.66	41	3.32
Maglev (Demand 0,1,6 higher)	733	59.91	326	26.66	41	3.32

Station #6





Total Passenger Travel Time (Status quo)	hour
Demand Even	3155
Demand 1,3,6 higher	5385
Demand 1,6 higher	7720

	Stop All		Stop 0,1,3,6		Stop 0,1,6	
	hour	percent	hour	percent	hour	percent
Incremental (Demand Even)	1005	31.86	1005	31.86	1005	31.86
Incremental (Demand 0,1,3,6 higher)	1646	30.56	1646	30.56	1646	30.56
Incremental (Demand 0,1,6 higher)	2261	29.29	2261	29.29	2261	29.29
Mini Shinkansen (Demand Even)	1068	33.86	1068	33.86	1068	33.86
Mini Shinkansen (Demand 0,1,3,6 high)	1788	33.21	1788	33.21	1788	33.21
Mini Shinkansen (Demand 0,1,6 higher)	2514	32.57	2514	32.57	2514	32.57
Full Shinkansen (Demand Even)	1714	54.33	1508	47.81	1039	32.93
Full Shinkansen (Demand 0,1,3,6 high)	2845	52.84	3005	55.81	2337	43.41
Full Shinkansen (Demand 0,1,6 higher)	3967	51.39	4258	55.16	4155	53.82
Maglev (Demand Even)	1907	60.46	1756	55.67	1238	39.24
Maglev (Demand 0,1,3,6 higher)	3212	59.65	3507	65.13	2785	51.72
Maglev (Demand 0,1,6 higher)	4545	58.87	5025	65.09	4951	64.14

Findings:

- In the scenario #10, which assumes balanced OD demand between cities and trains stop at all stations, higher maximum speed bears more time saving benefits. However, the marginal benefit is diminishing as the maximum speed increases. Although the Maglev bears the largest passenger time saving benefits, upgrading existing tracks to Incremental HSR will be the most cost-effective.

- The advantage of Mini Shinkansen to Incremental HSR is the elimination of physical transfer by the passengers. However, the magnitude of this advantage on travel time may not be large. Under the assumptions we used in the model, the difference between Incremental HSR and Mini Shinkansen on passenger time savings is relatively small. However, this situation may be changed if we consider the following two qualitative impacts; passengers' comfort gained by eliminating physical transfer, and improvement in the psychological accessibility of the region. The latter impact can be gained by HSR trains which directly connect the region to a large metropolitan area such as Tokyo.

- In the scenario #11 that allows Full Shinkansen and Maglev to skip stations, the time savings gained by Mini Shinkansen and Full Shinkansen are in the same order. In the scenario #12, the time saving by Full Shinkansen or Maglev is less than that by Mini Shinkansen. This fact implies that stations should not be skipped when OD demand is distributed equally throughout the corridor.

- In the scenario #13, #14, #15, which assume OD demand between city 0,1,3,6 are relatively higher, the passenger time savings will be larger than in the scenario #10, #11, #12, because the average travel length of passengers is longer. In terms of Full Shinkansen and Maglev, the scenario #14 bears more time savings than the scenario #15 that lets trains skip city 3. To maximize passenger time savings, it is necessary to stop at all the cities that have relatively large ridership.

- In the scenario #16, #17, #18 with extremely high demand between city 0, 1 and 6, time savings by the Maglev is the largest regardless of the stopping pattern. However, the time savings in the scenario #18, which allows trains stop all the stations, is larger than in the other two scenarios.

- When we focus on stopping pattern, it is shown that the strategy that allows all trains to stop all stations is the most beneficial to the entire corridor in term of passenger travel time savings, regardless what demand pattern in the three is applied. This is partly because we set the distance between stations considerably long in the hypothetical regions. If the distance is much smaller, the station skipping will have more impacts on travel time.

- When we focus on each station, the best strategy for stopping pattern might be different among stations. For the station 0, 2, 4 and 5, the strategy to let all trains stop every station always bears more passenger time savings. On the other hand, for the station 1, 3 and 6, skipping stations might bear more time savings when travel demand among city 0, 1 and 6 are much higher.

- In terms of different technologies, we can say that the high-technology and faster service generally bears more passenger time savings. However, it is the only an aspect to determine the whole time savings; for example, the passenger demand pattern and operational plan (i.e. skipping stations) are also important factors to determine the passenger time savings. It is very important to observe passengers' demand pattern and to fit the operational plan into it for maximizing time saving benefits.

- In general, the faster service bears more time savings, but at higher cost. It is generally noted a strategy that makes trains to stop all the stations gains more time savings for the whole corridor. For example, even when the demand between city 0, 1 and 6 is extremely higher as in the scenario #16, #17, #18, we saw the total time saving is larger when trains stop at all stations.

4.4 Conclusion

In this chapter, methods to calculate time saving benefits by various HSR technologies were discussed and analyzed by using two models and hypothetical regions. We found that the maximum speed as well as acceleration and deceleration rate is very important to assure high level of service, since attracting more passengers by reduction in travel time is the key for success of high-speed rail. It is also noted that operational plans such as skipping stations en route might have certain impacts on travel time, and HSR operation plan for a specific route should be decided with the real demand pattern along that route. In particular, we found that the station skipping strategy is effective when the travel demand is very unbalanced in origin-destination station pairs. If the travel demand is evenly spread throughout the region, the skipping intermediate station may not be a good strategy. In the next chapter, we will discuss the Tohoku region in Japan as a case study of high-speed rail implementation.

5. Case Study - Tohoku Region, Japan

In this chapter, the Tohoku region in Japan will be discussed. It is the only region that Mini Shinkansen lines are currently in operation and we will try to implement the concepts of travel time savings developed in the previous chapters. We will also refer to the possibility of making daily return trip by HSR, which may boost the impact of HSR as discussed in the literature review.

5.1 Geography

The Tohoku region is the northern part of Honshu, the main island of Japan; its area is 66,880 km^2, 17.7 % of Japan.(See Figure 5-1) The region includes 6 prefectures: Fukushima, Miyagi, Yamagata, Iwate, Akita, and Aomori.(See Figure 5-2) The largest city in the region is Sendai, in Miyagi prefecture.

The population in Tohoku region was 9,830,000 in 1995 and consisted 7.8% of the national total. (MITI[112], 1997) However, the increase rate of population between 1990 and 1995 was smaller than the national average except in Miyagi prefecture.(See Figure 5-3) It is noted that concentration of population into city area has been observed in the region. The population in larger cities have increased while population in counties of rural area has decreased. (See Figure 5-4) The increase of population in the 10 largest cities are above national average (1.6%) except in Iwaki and Hachinohe. (See Table 5-1)

However, there is less population of working age in Tohoku region compared to the national average. (See Figure 5-6) Low level wages in the region might be a reason why people do not stay in the region. The average income per person in Tohoku region is only 81.6% of the national average.

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[112] Source: Ministry of International Trade and Industry, Tohoku Branch (1997), "Tohoku Keizai no Point (An overview of Tohoku regional economy)" (in Japanese)

Figure 5-1: Japan's Population Density and Tohoku Region in Japan

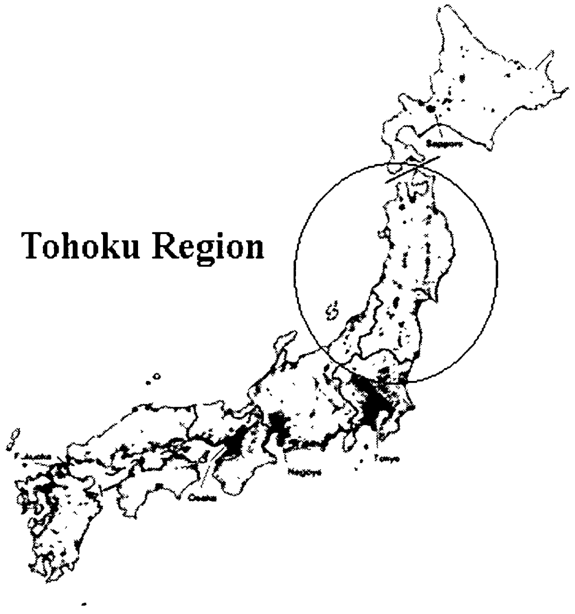


Figure 5-2: Six Prefectures in Tohoku region

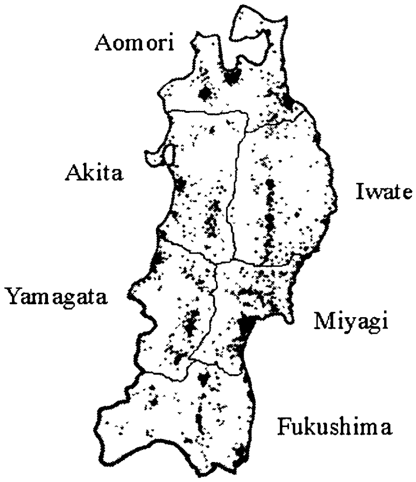


Figure 5-3: Population Change between 1990 and 1995

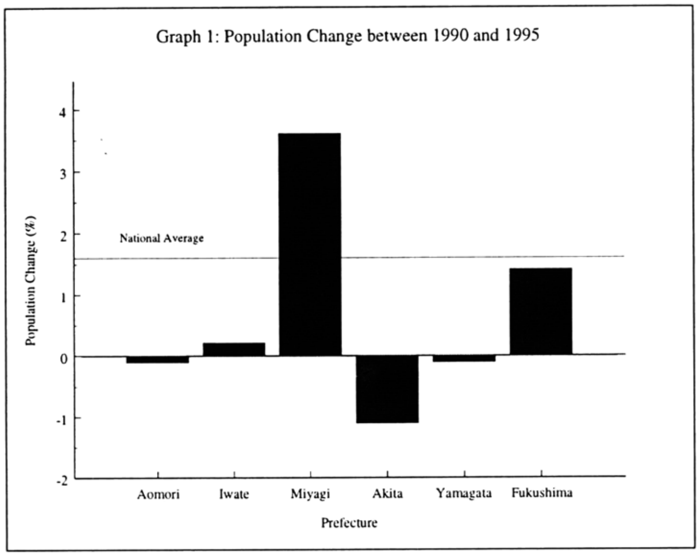


Figure 5-4: Trend of Population Change in Tohoku by City Size

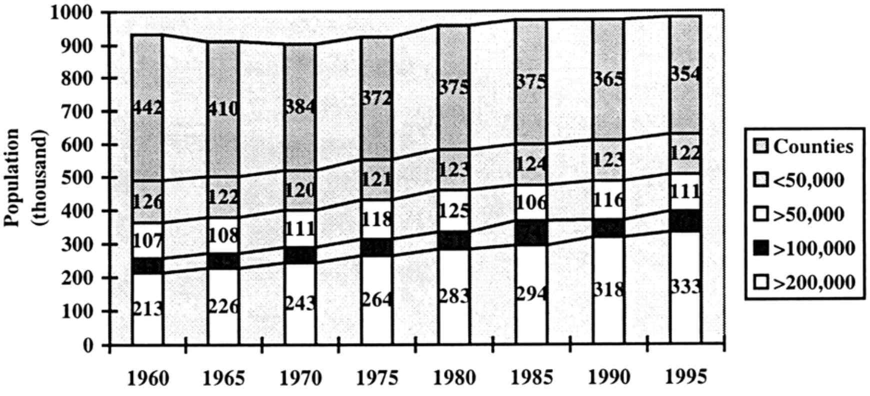


Figure 5-5: 10 Largest Cities in Tohoku Region

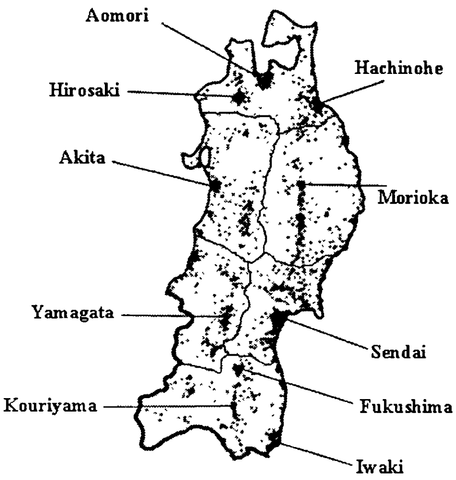
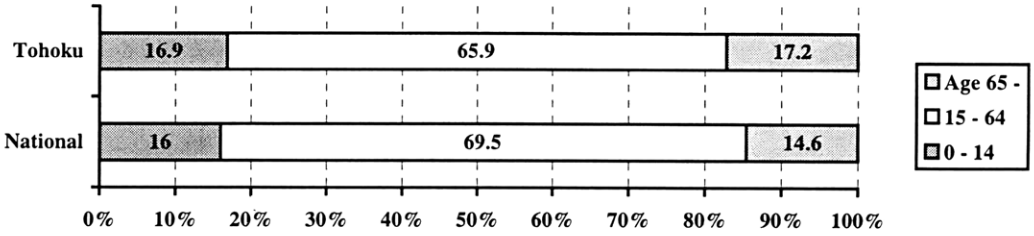


Table 5-1: Population in 10 large cities (1995)

City	Population	Increase[♦] (%)
Sendai	970,000	5.8
Iwaki	360,000	1.3
Akita	310,000	3.2
Kouriyama	302,000	3.9
Fukushima	290,000	3.0
Morioka	290,000	2.9
Aomori	290,000	2.2
Yamagata	250,000	2.0
Hachinohe	240,000	0.7
Hirosaki	180,000	1.9

[♦] Population increase between 1990 and 1995

Figure 5-6: Tohoku Population by Age



The regional economic situation has been not good for decades. As with other peripheral areas of Japan, the region has suffered from decrease of population especially in rural counties, and indexes imply that less economic growth has been gained in this region, when compared other regions in Japan.

The gross regional products in Tohoku region is 30.537 trillion yen which is 6.5 % of GDP in 1993. Note that the regional population is 7.8 % of the nation; this implies the average product per person in this region is below than national average. However, the size of regional product is in the same order of that of Switzerland. (See Figure 5-8) Figure 5-9 shows that the share of agricultural products is larger in the region.

Average income per person is 81.6% of national average. In particular, it is 77.8% of national average in the northern Tohoku (Aomori, Iwate, Akita prefectures) while 85.4% in the southern Tohoku (Miyagi, Yamagata, Fukushima prefectures). This implies that the northern area of the region suffers severer economic condition. One reason for this would be the limited accessibility from other regions, especially from Tokyo area. The south Tohoku area is well connected to Tokyo in Kanto region with Shinkansen and highways, while the northern area does not have transportation infrastructure to allow the same-level accessibility. It is noted that 45 factories and research laboratories of international companies in the Tohoku region; 38 of them are located in the southern Tohoku. Only 7 locate in North Tohoku, but all of them are in Iwate prefecture, which has Tohoku Shinkansen in its region[113]. (See Figure 5-10) This fact implies that accessibility might be a key to the regional development.

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[113] Ibid. 112

Figure 5-7: Tohoku region in the whole nation

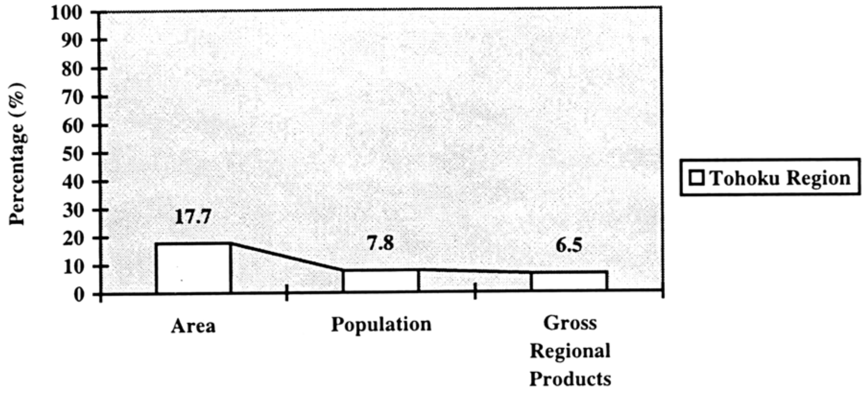


Figure 5-8: Size of Gross Regional Products

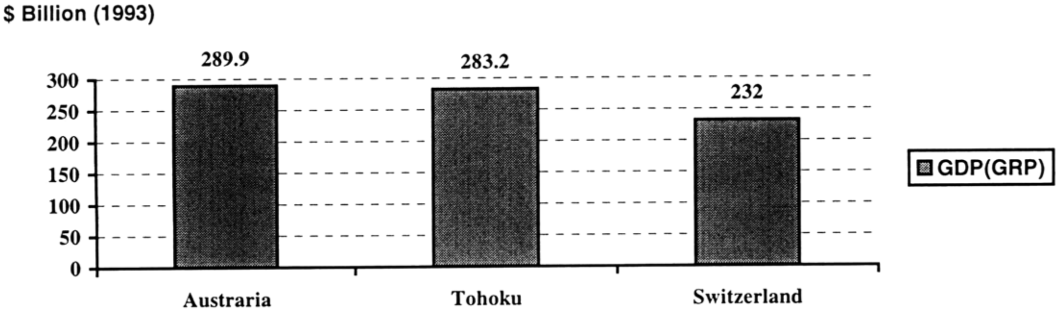


Figure 5-9: GDP and Gross Regional Products

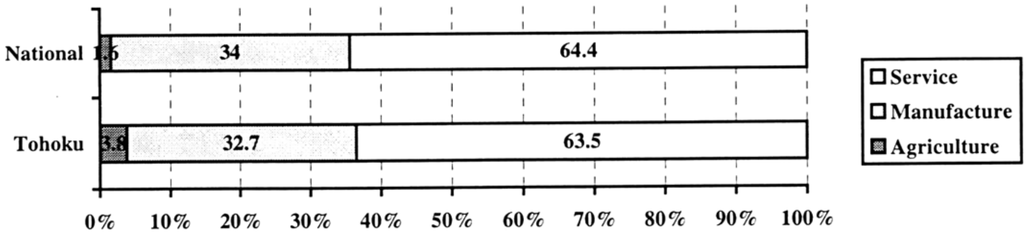
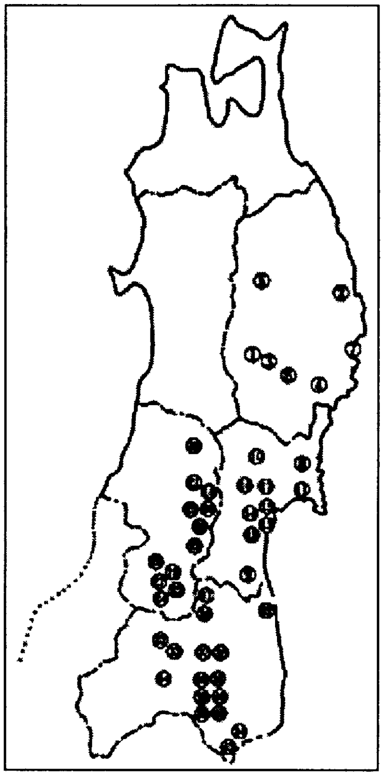


Figure 5-10: Factories and Laboratories owned by international capital[114]



5.2 Transportation Infrastructure

The Tohoku region has three primary intercity passenger transportation networks: railway, air, and highways.

5.2.1 Railroad

Before the construction of Tohoku Shinkansen, the narrow-gauge (1.067 meter) railroad network was operated by the Japan National Railroads(JNR) for long-distance passenger transportation in the Tohoku region. Since the completion of Tohoku Shinkansen in 1982, the parallel narrow-gauge rail route has been used mainly for medium distance passenger transportation and long distance freight transportation.

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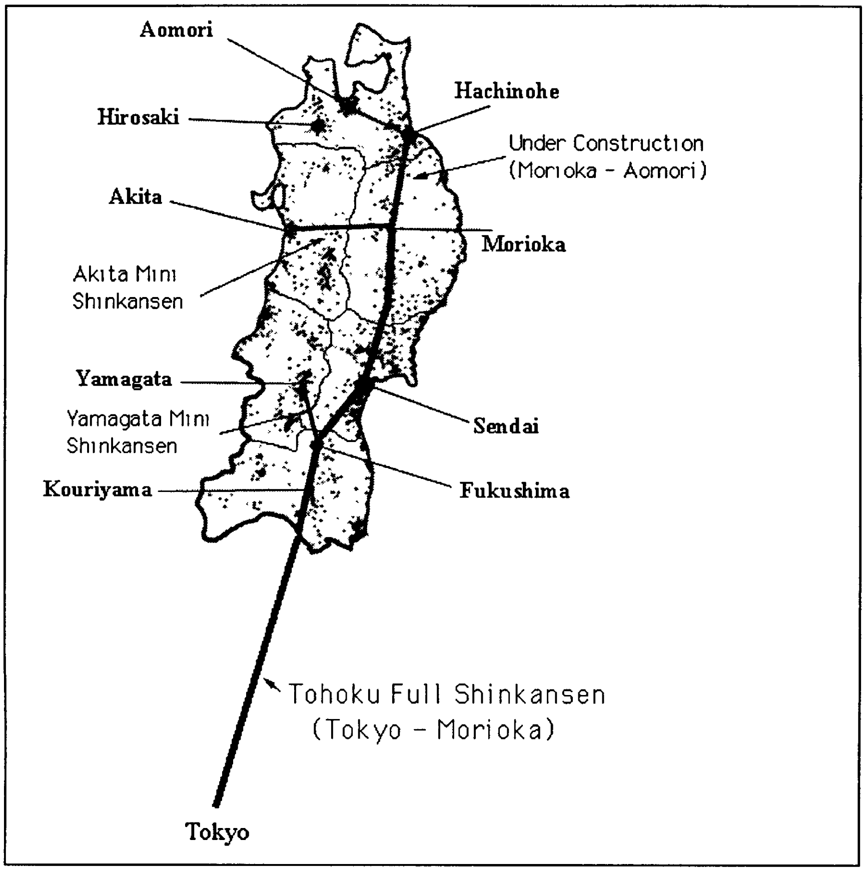
[114] Source: Ibid. 112

Although there have been some rail agencies for intra-city transit, JNR or JR-East, its successor in the Tohoku region, has been a dominant passenger rail agency operating both Shinkansen and narrow-gauge networks.

In less than two decades, the Shinkansen network including Mini Shinkansen lines has expanded in the region. Tohoku Full Shinkansen started in 1982; Yamagata Mini Shinkansen began operation in 1992, and Akita Mini Shinkansen in 1997. The Shinkansen network has covered five prefectures out of six in the Tohoku region; only Aomori, the north-end prefecture does not have Shinkansen currently. At the city level, six of the ten largest cities have been covered by the Shinkansen network. Tohoku Full Shinkansen runs from Tokyo to Morioka through Kouriyama, Fukushima, Sendai. Yamagata Mini Shinkansen connects Fukushima and Yamagata, and Akita Mini Shinkansen connects Morioka and Akita. Furthermore, construction of Full Shinkansen is proceeding from Morioka to Hachinohe in Aomori prefecture, and further extension to Aomori city is now planned.

Here, Tohoku, Yamagata, Akita Shinkansen and their impacts on regions are discussed. The extension of Tohoku Shinkansen to Aomori is also discussed.

Figure 5-11: Shinkansen Network in Tohoku Region



5.2.1.1 Tohoku Full Shinkansen

Tohoku Full Shinkansen runs from Tokyo to Morioka through Tohoku region from south to north like a backbone and connects Tohoku region with Tokyo metropolitan area. (See Figure 5-11) It started revenue service in 1982 partially from Morioka to Omiya, in suburban Tokyo. It was extended to Ueno in 1985, and finally to Tokyo in 1991. It was the first Seibi Shinkansen project, whose main purpose was assuring equity in accessibility and opportunity for economic development among regions in Japan. This Shinkansen was constructed as a Full Shinkansen.

The Tohoku Shinkansen line connects 4 out of the 10 largest cities in Tohoku region: Kouriyama, Fukushima, Sendai and Morioka. All trains stop at Sendai, the center city of the Tohoku region. It is noted that the travel demand between Tokyo and Sendai is higher than between

Sendai and Morioka. It can be seen from the difference in number of train running on two segments. (See Table 5-2)

Table 5-2: Number of trains operating daily on the Tohoku Full Shinkansen line[115]

segment of route	Northbound	Southbound
Between Tokyo and Sendai	56	54
Between Sendai and Morioka	32	31

The stopping pattern of Tohoku Shinkansen is much complicated; some train stops all the stations while the other express-type trains skip some stations. However, all trains stop at Sendai station, the regional center.

Table 5-3: Number of Express-type Trains♦ running daily on the Tohoku Full Shinkansen line[116]

segment of route	Northbound	Southbound
Between Tokyo and Sendai	10 (18 %)	10 (19 %)
Between Sendai and Morioka	11 (34 %)	10 (32 %)

Travel time also varies among trains, depending on the number of stations skipped.

Table 5-4: The difference in travel time between Express and normal Shinkansen

segment of route	Express type	Normal type (stops all)
Between Tokyo and Sendai	1 hour 36 minutes (Fastest)	2 hours 29 minutes
Between Sendai and Morioka	44 minutes (Fastest)	1 hour 18 minutes

It has been more than 15 years since the Tohoku Shinkansen line began its operation. Currently, it is the dominant mode between Tokyo and Sendai or Morioka because no daily flights are available on the competing route. There is a bus route between Tokyo and Sendai, but the frequency is only one per day, and it carries negligible traffic. It can be said that most business travelers in the region use Tohoku Shinkansen to Tokyo.

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[115] Source: JR-Timetable (1997), December (in Japanese)

♦ The trains that stop only at Tokyo, Ueno, Omiya, and Sendai.

[116] Ibid. 115

After the completion of Tohoku Shinkansen, daily return trips from Iwate prefecture to Tokyo area became possible. Before the Shinkansen, most of business travelers from Iwate spent 2 nights when going to Tokyo; one night on the night-train, and other night in Tokyo. After the Shinkansen, most of them returns Iwate in the same day using Shinkansen. (Tsuchiya et al. 1997[117])

However, an interesting fact is that a bus route operating between Sendai and Morioka has been in a good condition. This non-stop service between two cities takes 2 hours and 50 minutes and is much slower than the Shinkansen trains, but the frequency of this bus service is 14 per day and the fare is much cheaper than Shinkansen. (2,850 yen while Shinkansen costs 6,290 yen) Non-business travelers might select this bus service because of the cheaper fare. The road congestion in Tohoku region is generally not severe compared with the Tokyo metropolitan area, and the on-time performance of this service is acceptable.

In terms of impacts on the Tohoku region, recent evaluation of Tohoku Shinkansen line in the northern Japan revealed that the Shinkansen was associated with the strongest population gains in small- and medium-sided cities. (Sawada[118], 1995) According to Cervero and Bernick[119](1996), Nakamura and Ueda(1989) revealed that per capita income growth increased significantly relative to regional averages in areas with Shinkansen(2.6%), an express way(6.4%), or both(9.5%); regions with neither Shinkansen nor expressways experienced a decline (-2.7%) in per capita income.

5.2.1.2 Yamagata Shinkansen

The Yamagata Shinkansen line is the first Mini Shinkansen in Japan. The construction started in 1989 and the revenue operation began in 1994. Between Fukushima and Yamagata, there are four stations for Yamagata Mini Shinkansen; Yonezawa, Takahata, Akayu, and Kaminoyama-Onsen. The distance between stations is 40.1 km (Fukushima to Yonezawa), 9.8 km (Yonezawa

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[117] Tsuchiya, Takano, Sato(1997), "Tohoku Shinkansen no Kaigyo ni yoru Koryu Kino no Kakudai ni kansuru Jisho teki Kenkyu", Japanese Association of Civil Engineers, 52nd Annual Conference, Sep. pp.402 (in Japanese)

[118] Sawada, Jun(1995), "Effects of Shinkansen Construction on Regional Development", *Rail International*: August, September, pp.31-37

[119] Ibid. 42

to Takahata), 6.2 km (Takahata to Akayu), 18.9 km (Akayu to Kaminoyama-Onsen), and 12.1 km (Kaminoyama-Onsen to Yamagata).

Except for the Mini Shinkansen express trains, the travel demand for local trains on the route has not been so high, because it crosses a mountainous area between Fukushima and Yonezawa. Only 6 local trains a day are running between Fukushima and Yamagata directly, and more trains run near the Yamagata station to serve regional commuting demand. Most passengers of local trains are students since they don't have alternative mode of transportation.

From these facts, the purpose of the Yamagata Mini Shinkansen line is not to integrate intra-regional economy by connecting adjacent cities with high frequency, because the region is not mature enough to allow such strategy. Instead, the main purpose of the Yamagata Mini Shinkansen is to improve regional accessibility to other regions especially to Tokyo to improve the regional economy. In that sense, the implementation of this Mini Shinkansen reduced both physical distance and psychological accessibility of the region. Physical distance has been shortened by the reduction of travel time, and psychological distance has been also shortened somewhat by the fact that the region has trains running directly to Tokyo terminal.

In terms of operational speed, there remains significant speed restriction on the route. At Itaya *toge*, a steep mountain pass, the limited speed is 70 km/h on the northbound (60 km/h on the southbound) due to the steep curve and gradient. The length of route that a train can run at 130 km/h is only 27.4 km (31%) on the northbound and 40.1 km (46%) on the southbound.[120] Fifteen trains run daily on the route, connecting Yamagata and Tokyo directly. However, the number of express type trains that stops only at Fukushima and Yamagata is 2 for both direction.

Table 5-5: Number of trains operating daily on the Yamagata Mini Shinkansen line[121]

	Northbound	Southbound
Daily number of trains	15	15
Express type	2	2

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[120] Source: *Tetsudo Journal* (Railway Journal) (1997): June,pp.30-36 (in Japanese)

[121] Ibid. 115

Table 5-6: Time Table of Yamagata Shinkansen (as of December 1997)

Departing time at Yamagata	6:25	7:11	7:59	8:51	9:48
Number of Stops[♦]	4	0	4	4	3
Arriving time at Fukushima	7:36	8:14	9:10	10:06	10:57
Arriving time at Tokyo	9:23	9:40	10:52	11:51	12:40
Travel time	2h58	2h29	2h53	3h00	2h52
Number of stops en route	9	1	8	9	8
Departing time at Yamagata	11:09	12:29	13:24	14:08	15:22
Number of Stops	3	1	3	3	3
Arriving time at Fukushima	12:19	13:34	14:32	15:17	16:31
Arriving time at Tokyo	14:04	15:16	16:08	17:00	18:16
Travel time	2h55	2h47	2h44	2h52	2h54
Number of stops en route	8	6	7	8	8
Departing time at Yamagata	16:44	17:09	18:12	19:31	20:11
Number of Stops	3	3	4	0	3
Arriving time at Fukushima	17:53	18:19	19:25	20:35	21:20
Arriving time at Tokyo	19:36	20:04	21:10	22:18	22:54
Travel time	2h52	2h55	2h58	2h47	2h43
Number of stops en route	8	8	9	5	6

Departing time at Tokyo	6:32	7:26	8:36	9:08	9:36
Departing time at Fukushima	8:03	8:52	10:22	10:46	11:22
Number of Stops	3	0	4	1	3
Arriving time at Yamagata	9:10	9:53	11:30	11:48	12:28
Travel time	2h38	2h27	2h54	2h40	2h52
Number of stops en route	6	1	8	5	8
Departing time at Tokyo	10:12	11:04	12:04	13:12	14:16
Departing time at Fukushima	11:55	12:45	13:46	14:55	15:59
Number of Stops	3	3	3	4	3
Arriving time at Yamagata	13:06	13:50	14:53	16:03	17:05
Travel time	2h54	2h46	2h49	2h51	2h49
Number of stops en route	8	8	8	9	8
Departing time at Tokyo	15:36	16:20	17:16	18:28	20:16
Departing time at Fukushima	17:20	18:05	19:03	20:14	22:02
Number of Stops	3	0	4	3	4
Arriving time at Yamagata	18:27	19:07	20:10	21:20	23:09
Travel time	2h51	2h47	2h54	2h52	2h53
Number of stops en route	8	5	9	8	9

For business travelers, it is important whether they can make a daily return trip. It is natural to assume the majority of business travelers from this region make their trips to Tokyo metropolitan area, when using Mini Shinkansen. We found that the daily return trip can be done without any difficulty. The example of convenient trains for these trips is as follows;

[♦] between Yamagata and Fukushima

Table 5-7: Combination of trains for one-day return trip and stay time in Tokyo

Departing time at Yamagata	7:11	7:59	8:51	9:48	11:09
Arriving time at Tokyo	9:40	10:52	11:51	12:40	14:04
Stay time	**4h36**	**4h44**	**4h29**	**4h36**	**4h30**
Departing time at Tokyo	14:16	15:36	16:20	17:16	18:34
Arriving time at Yamagata	17:05	18:27	19:07	20:10	21:20

It can be seen that one day return trip between Yamagata and Tokyo is reasonable. The combinations of trains can be changed to make the stay in Tokyo longer.

The ridership has increased after the completion of Yamagata Shinkansen, and to cope with the more demand, one additional car was added to every train; 7 cars for each train in 1994. (See Table 5-8)

Table 5-8: Ridership on Yamagata Shinkansen[122] (between Fukushima and Yonezawa)

Year	Daily Ridership	Travel time	Seating Capacity	Utilization rate
1989	3,200	3 hours 15 min.	4,500	71.1 %
1992	4,500	2 hours 27 min.	4,700	95.7 %
1996	4,500	2 hours 27 min.	6,000	75.0 %

The change in the number of rail and air passengers before and after the completion of Yamagata Shinkansen is shown in Table 5-9. It can be seen that the user of airplane between Tokyo and Yamagata has decreased significantly. The number of daily flight between Tokyo and Yamagata has also decreased from 5 to 2 as of 1997. While the number of automobile users is not known, the total number of railway and air passengers between Tokyo and Yamagata has increased after the Yamagata Shinkansen.

Table 5-9: Change of passengers between Tokyo and Yamagata[123] (in thousands)

	1990	1995	Increase
Railway	1,860	2,101	241
Air	438	270	-168
Total	2,298	2,371	73

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[122] Ministry of Transport(1997), "Unyu Keizai Nenji Hokoku (Transportation Economics Annual Report)", November (in Japanese)

[123] Ibid. 122

According to the Ministry of Transport[124], the decrease of flights from Yamagata to Tokyo has resulted in increase of flights from Yamagata to other destinations. In fact, flights from Yamagata to Osaka has increased after the Yamagata Mini Shinkansen.

JR-East[125](1997), the company which operates Yamagata Shinkansen, claims that it has enjoyed increased number of passengers.

> *The route has greatly reduced the travel times and eliminated the need to change trains, enabling JR East to capture a greater share of this transportation market. Recent figures show around a 20 % increase in annual passenger volume between Tokyo area and Yamagata compared to figures before through service was initiated.*
> *The reduction from 5 to 3 in daily flights from Tokyo to Yamagata also proves the line's popularity.*

Extension of Yamagata Shinkansen

The increase in ridership of the Yamagata Mini Shinkansen has demonstrated the impacts of Mini Shinkansen and its application to other regions, and the extension of Yamagata Shinkansen toward Shinjo was decided upon in 1997. The number of passengers would be less than that of the existing Yamagata Mini Shinkansen, and the local governments have decided to cover the financial risks of the project partially.

5.2.1.3 Akita Shinkansen

The Akita Shinkansen started commercial services on 22 March from Morioka to Akita, and its route length is 127km. Among the 13 daily Tokyo-Akita services in each direction, three link both cities in less than four hours and JR East hopes to take back passengers from airlines. The fastest train runs 662.6 km in 3 hours 55 minutes.

The 75 km single-track of the route was widened to standard gauge. The remaining 57 km was double-track route, and 39 km of it were rebuilt into parallel standard-gauge and narrow gauge single tracks. The other 13 km was converted into one standard-gauge single track and one mixed gauge single track, allowing Shinkansen trains to pass each other[126]. The maximum speed

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[124] Ibid. 122

[125] East Japan Railway Company(1997), "Annual Report 1997":p.19

[126] Source: *Japan Railway & Transport Review*(1997), published by East Japan Railway Culture Foundation, April, No.11, pp.66

on the Akita Shinkansen is 130 km/h, but journey time between Tokyo and Akita is cut by 40 minutes by eliminating the train change at Morioka Station and by raising the maximum speed on the Tohoku Shinkansen from 240 to 275 km/h. Each trainset has 5 cars in configuration and run on the Tohoku Shinkansen coupled with 8-car or 10-car Full Shinkansen trainsets.

Table 5-10: Time Table of Akita Shinkansen (as of December 1997)

Departing time at Akita	6:12	7:28	8:14	9:22	10:27
Number of Stops	4	3	3	4	3
Arriving time at Morioka	7:44	8:57	9:49	11:02	12:01
Arriving time at Tokyo	10:36	11:23	12:44	13:48	14:44
Travel time	4h24	3h55	4h30	4h26	4h17
Number of stops en route	10	6	9	8	7
Departing time at Akita	11:56	12:42	13:14	14:13	15:12
Number of Stops	3	1	3	3	4
Arriving time at Morioka	13:23	14:08	14:54	15:54	16:50
Arriving time at Tokyo	16:24	16:31	17:36	18:48	19:44
Travel time	4h28	3h49	4h22	4h35	4h32
Number of stops en route	10	3	7	7	11
Departing time at Akita	16:51	17:22	18:13		
Number of Stops	1	3	3		
Arriving time at Morioka	18:17	18:56	19:43		
Arriving time at Tokyo	20:44	21:52	22:38		
Travel time	3h53	4h30	4h25		
Number of stops en route	4	9	10		

Departing time at Tokyo	6:50	8:00	8:52	9:56	10:48
Departing time at Morioka	9:36	10:28	11:48	12:47	13:34
Number of Stops	3	3	4	3	3
Arriving time at Akita	11:16	11:55	13:32	14:35	15:10
Travel time	4:26	3:55	4:40	4:39	4:22
Number of stops en route	7	6	10	7	7
Departing time at Tokyo	11:44	12:56	14:00	14:56	15:28
Departing time at Morioka	14:42	15:20	16:51	17:42	18:25
Number of Stops	3	1	4	3	3
Arriving time at Akita	16:19	16:45	18:32	19:19	20:07
Travel time	4:35	3:49	4:32	4:23	4:39
Number of stops en route	9	3	11	9	9
Departing time at Tokyo	16:36	17:44			
Departing time at Morioka	19:23	20:11			
Number of Stops	3	1			
Arriving time at Akita	20:58	21:35			
Travel time	4:22	3:51			
Number of stops en route	7	4			

It is too early to decide the impacts of the Akita Mini Shinkansen, but in terms of one day return trip from Akita to Tokyo, it is possible but harder than the Yamagata Shinkansen case.

Table 5-11: Combination of trains for one-day return trip and stay time in Tokyo

Departing time at Akita	7:28	8:14
Arriving time at Tokyo	11:23	12:44
Stay time	**5h13**	**5h00**
Departing time at Tokyo	16:36	17:44
Arriving time at Akita	20:58	21:35

The competition between air would be more severe for business travelers, although higher frequency is the advantage of Akita Mini Shinkansen.

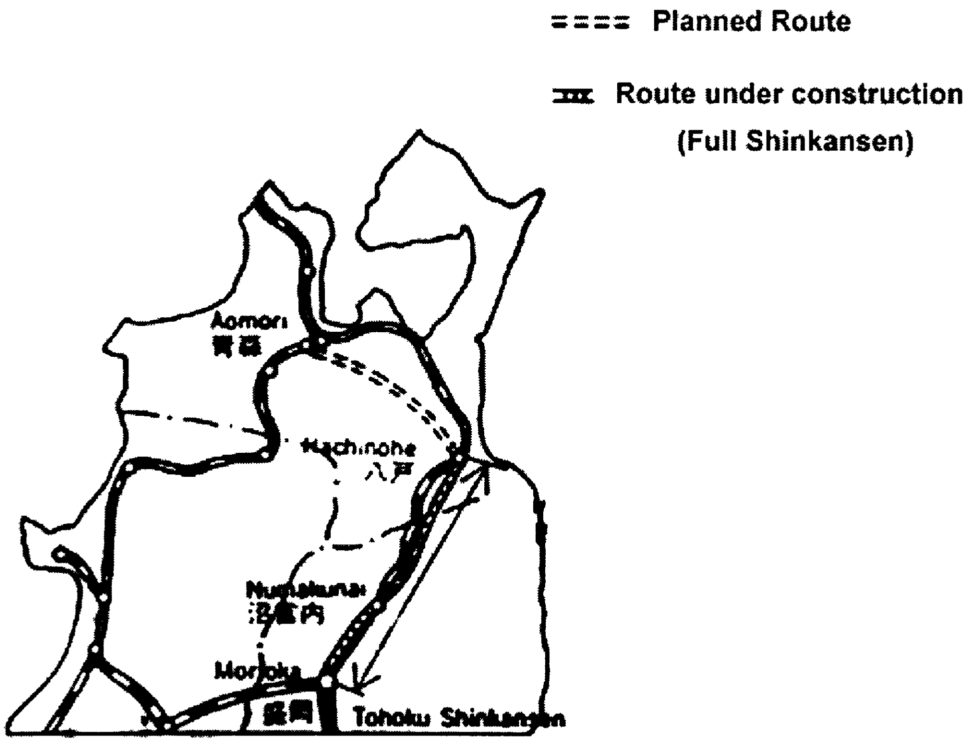
Table 5-12: Combination of flights for one-day return trip and stay time in Tokyo

Departing time at Akita	8:40	10:10
Arriving time at Tokyo	9:50	11:15
Stay time	**5h35**	**6h50**
Departing time at Tokyo	15:25	18:05
Arriving time at Akita	16:25	19:05

5.2.1.4 Extension of Tohoku Shinkansen

The Seibi Shinkansen Law included a plan to extend Tohoku Shinkansen to Aomori, the northern end of Tohoku region, and ultimately to Hokkaido region. (See Figure 2-2) There are two routes currently under construction. One is between Morioka and Hachinohe, and the other is between Hachinohe and Aomori. The route between Morioka and Hachinohe is decided to be constructed as Full Shinkansen, while the other route between Hachinohe and Aomori is not decided yet. Local governments including Aomori prefecture have demanded Full Shinkansen to Aomori, but its higher construction cost is the obstacle..

Figure 5-12: Tohoku Shinkansen Extension Plan



5.2.2 Highway

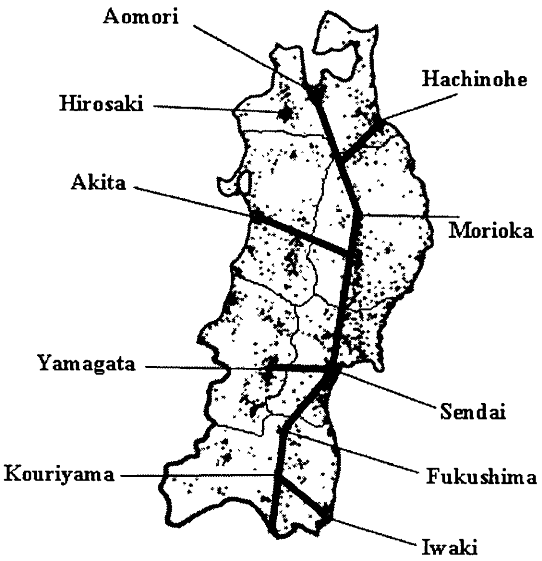
The highway network has been expanding in the region. The construction of the highway network has been easier than that of Shinkansen because of benefits to a broader population. The construction of backbone routes is almost done and the present concern is construction of connecting highways.

However, for the passenger transportation, intercity highway bus is not common in the region. There is no daytime interregional service by bus. Exceptions are two intra-regional routes; Sendai to Morioka and Morioka to Hirosaki. The bus route between Sendai and Morioka operates 14 buses daily with 2 hours 50 minutes. This service directly competes with Tohoku

Shinkansen of higher speed and more frequency. The travel time by bus is much longer than Shinkansen (only 44 minutes). However, the fare of bus is 2,850 yen ($22) while the fare of Shinkansen is 6,290 yen ($48) and the bus service has made a considerable success.

On the other hand, the bus route between Morioka to Hirosaki has no rivals. It operates 15 buses a day, and it is much superior to rail in terms of travel time, frequency, and fare.

Figure 5-13: Highway Network in Tohoku Region



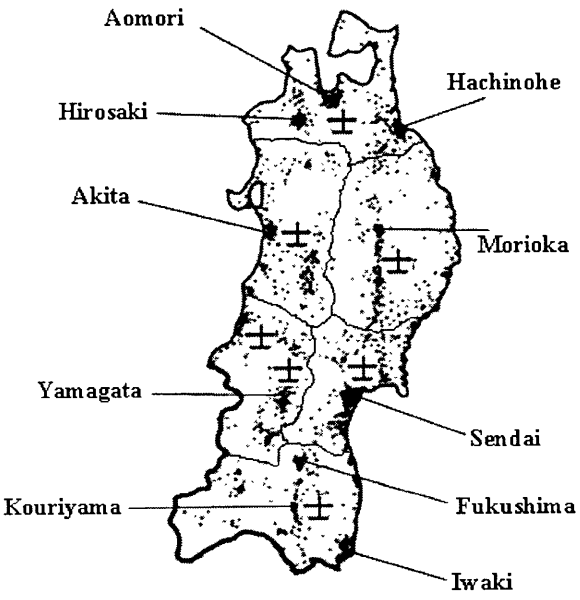
5.2.3 Air transportation

Demand for air travel has been increasing. However, because of very fierce opposition for airports due to noise problem, it is very time-consuming and costly to increase capacity of airports in metropolitan area. In fact, two airports in Tokyo have already reached maximum capacity and cannot cope with increased international demand. As a result, capacity increase in local airports does not necessarily result in the increase of flights especially to metropolitan area.

Table 5-13: Number of Daily Flights from Airport in Tohoku Region[127]

Origin Airport	Destination	Tokyo	Nagoya	Osaka	Fukuoka
Fukushima	Fukushima	0	1	2	1
Sendai	Miyagi	0	5	8	4
Hanamaki	Iwate	0	1	2	0
Yamagata	Yamagata	2	1	2	0
Shonai	Yamagata	3	0	0	0
Misawa	Aomori	4	0	1	0
Aomori	Aomori	6	1	2	0
Akita	Akita	6	0	2	0

Figure 5-14: Airports in Tohoku Region



In Japan, air transportation is not a dominant mode because of the limited capacity of airports, especially in large metropolitan areas. For example, both Haneda and Narita Airports have almost reached their capacity, but expansion of these airports entails significant costs because of political, environmental and geographical constraints. Therefore, it is not likely that the capacity of air transportation increase significantly and the congestion of air traffic will continue.

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[127] Ibid. 115

The other problem of air transportation is the bad access of airports in Tokyo. The Narita international airport is more than 50 km away from CBD of Tokyo and takes 1 hour on express train. Haneda airport is much closer to CBD, but no direct transit service to CBD is available.

Those aspects of air transportation gives railroad significant advantage in Japan. The modal share of HSR is dominant at the distance of 300 km to 700 km.

5.3 Conclusion

The Tohoku region and its intercity transportation modes were discussed in this chapter. The characteristics of the Shinkansen network and its impacts on the Tohoku region were discussed. The empirical studies showed that Tohoku Full Shinkansen line with highway network has contributed to the regional development in terms of population increase and income per capita. The impacts of Mini Shinkansen lines on the regional economy has not become clear yet, but considerable increase in ridership has been observed along the routes.

6. Conclusion

This chapter concludes the thesis, which has investigated high-speed rail and regional development. Firstly, we briefly summarize the principal findings, which are drawn from the preceding chapters. The section that follows gives a final summary, contribution of this thesis, and future area of study.

6.1 Findings

- **The high-speed rail is currently an important option for efficient intercity passenger transportation around the world.**

This phenomenon is seen not only in Europe or Japan where rail transportation has been popular, but also in the U.S where automobiles and air transportation have been dominant in intercity passenger transportation market. The environmental concern and congested highways and air corridors have made more regions interested in HSR.

- **High construction costs have been a major obstacle for HSR implementation, but less costly options are now available.**

The high initial cost has been a significant hindrance for the implementation of HSR, because it is regarded as a large financial risk when demand is not assured. However, we now have less costly options such as Incremental HSR developed in the U.S. or Mini Shinkansen in Japan, which generate less construction cost compared to the traditional HSR which requires dedicated rights-of-way. Utilization of existing rights-of-way is a key to reduce the construction costs.

- **A HSR may have catalytic effects on regional economies.**

A HSR may perform a catalytic effect on the economic development; it may not be sufficient to cause the regional economic development, but it can trigger the development, especially where a bottleneck exists in terms of transportation capacity. The impacts of HSR on regional economy can be further classified into two different effects: re-distributive effects and generative effects.

The re-distributive effects are just transfer between regions at the national level, but it can be counted as a benefit of HSR for a specific region. On the other hand, if a HSR can reduce the production costs of private firms, it will have generative effects to improve their productivity and result in economic growth. A HSR also can generate new job opportunities for the regions.

- **Aggregate quantitative studies of the impact of high speed rail on regional economic development have not been performed.**

We did not find any empirical studies that attempted to isolate the impacts of HSR infrastructure investment on the regional economy in an aggregated level. It is probably due to the lack of the necessary data. Also, there is no country with extensive network of high-speed rail enough to compare with other public investment such as the highway network at national level analysis. Consequently, the analyses of HSR impact on regional development tend to be qualitative.

- **While cost benefit analysis is a useful tool for HSR in principle, it is also a complicated task. It can include external impacts of HSR, although methodologies vary and unanimous agreement on how to perform these analyses has not been gained.**

It is hard to perform an accurate cost-benefit analysis, due to the difficulties to define a system boundary and to allocate shared costs. The impacts of HSR on outside the system (e.g. congestion reduction, environmental impacts) are also difficult to derive, because causality is often unclear. The availability and accuracy of data is an another problem.

- **Travel time saving resulting from HSR implement is a function of many characteristics of a particular system.**

Travel time, which is a major variable for level of service, is an output of a complicated function using not only the maximum operational speed of the train, but many other characteristics such as acceleration and deceleration rate, distance between stations, or partial speed limits. Using the models and hypothetical regions, we found that raising maximum speed itself may not be enough to reduce the travel time effectively. It is necessary to see a HSR line as a whole system, and the suggested strategy might be different case by case.

- **Station skipping might have negative impacts on total passenger time savings.**

It is common in HSR operation to skip some stations to realize shorter travel time between distant stations. However, the advantage gained by the reduced travel time between cities may not exceed the disadvantages for the passengers using skipped stations. The decision of skipping stations needs a complete picture of travel demand en route and careful analysis.

- **The Tohoku region is utilizing the Shinkansen network to some extent.**

The Tohoku region in Japan currently has three Shinkansen routes and is planning to expand the network toward its north end with national and prefecture support. Although the impacts of the existing Shinkansen routes on the regional economy has not been clearly proved, the ridership of the routes has represented a satisfactory level of utilization. All possible methods to reduce the construction cost should be taken for the further construction of HSR.

Next, the whole thesis is briefly summarized chapter by chapter.

6.2 Summary

We discussed various high-speed rail technologies around the world, including the Japanese Shinkansen, the French TGV, the German ICE and the Northeast corridor project in the U.S. in Chapter 2. We found that many of these HSR services have received positive societal appraisals to some extent and further extension or integration of existing HSR network has been planned in these countries. Integration of the existing network has become a major issue for HSR in Europe and in Japan, and options with less construction cost have been proposed. In particular, we discussed the Mini Shinkansen option with construction cost only seven percent of normal Full Shinkansen project in Japan. It was noted that the magnitude of HSR success depends on the specific projects and reduction in construction cost has been very important, because feasibility of HSR project will always remain as a key issue, since demand prediction is always uncertain.

We reviewed literature about relationship between high-speed rail and regional development in Chapter 3. The review included studies of general relationship between transportation infrastructure investment and regional economic development, cost-benefit analysis methodologies for a HSR project, and case studies of specific HSR projects. Aggregated quantitative research for the relationship between high-speed rail and regional economic development was not found; instead we reviewed several studies using empirical data of general transportation infrastructure (e.g. highway network) and domestic or regional economy in the United States. We found that a HSR investment will have positive impacts on regional economy to some extent from the viewpoint of public infrastructure investment, but its magnitude may not be as high as other public investments. A careful cost-benefit analysis is necessary to assure the feasibility of any HSR projects, and general conclusions about the economic impacts by HSR are hard to establish.

The impacts of HSR technologies on passenger travel time were analyzed, since the time saving benefits has been considered as the primary benefit of HSR. We developed two analytical models and hypothetical regions. We analyzed several technologies including Incremental HSR, Mini Shinkansen, Full Shinkansen, and Maglev for the magnitude of time savings. We found that the operational plans as well as technology level have significant impacts on the travel time. The maximum speed of the trainset has significant impacts on travel time and passenger travel time savings, but other operational plans (e.g. station skipping) also have significant impacts on the travel time and the level of service offered by the HSR. An operational plan that meets travel demand of the route is very important to increase passenger travel time savings, which is the major benefit of HSR. It is also noted that station spacing is critical to utilize the potential of high-speed rail. The technology implemented in a corridor must be determined by the geography and pattern of demand.

The Tohoku region in Japan was discussed as a case study of HSR technologies and their impacts in Chapter 5. We discussed one Full Shinkansen line and two Mini Shinkansen lines in the region in terms of level of service and competition with other intercity transportation modes. We found that these HSR lines are enough competitive with air transportation and there are some evidences that air transportation has decreased its service. We conjecture that the Tohoku Shinkansen, the Full Shinkansen line in the region, has contributed to the regional development to some extent, although it is not decisive evidence.

In conclusion, the planning and construction of high-speed rail network is currently an important issue of passenger transportation. However, the implementation of high-speed rail is a mixed endeavor, and all wisdom must be coordinated for the realization of any HSR projects. It is necessary to integrate all the components of transportation to take the full advantage of high-speed rail. For example, the construction of high-speed rail itself is not enough; good access to its stations is necessary to attract more ridership. Maximizing the benefits as well as minimizing costs is critical issue for every HSR project. The discussion of HSR impacts still remains, and an integrated plan is necessary to ensure the benefits of HSR fully received.

An additional effort in the research is the conceptual model and hypothetical regions that we developed. These can be a simple but good analytical tool to understand the service design of rail transportation, in terms of the impacts of several features of HSR on travel time. They can be used to see the impacts of different operational plans in the HSR operation. This model is quite flexible and can incorporate various assumptions. The variables used in the model include maximum speed, acceleration ratio, deceleration ratio, distance between stations, and stations to be passed. The main output is travel time.

6.3 Future Research Area

- The model we used in the hypothetical regions are fairly simple, and more features of HSR operation can be improved. For example, the idea of setting partial speed limits between stations or assuming very short distance between stations can be used to make the model more realistic. In addition, the idea of frequency in train operation and weighting out-of-train waiting time more in terms of passengers travel time can be incorporated into the model. Then, we may find a different conclusion when we analyze the impacts of rail improvement projects on travel time and level of service.

- Further data analyses could be done by using the model. For example, different assumptions of the travel demand pattern could be analyzed. We examined three demand patterns in the analysis, but many other demand patterns would exist on a specific corridor and it may be useful to get insights of possible HSR implementation.

- There currently exists no study that investigates HSR impacts on a regional economy in an aggregated level. However, in the Europe or in Japan where HSR network has been more developed than in the previous decades, complete research that investigates this relationship directly would become possible if necessary data is obtained.

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