12-1-2014

Developing Seamless Connections in the Urban Transit Network: A Look toward High-Speed Rail Interconnectivity

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DEVELOPING SEAMLESS CONNECTIONS IN THE URBAN TRANSIT NETWORK: A LOOK TOWARD HIGH-SPEED RAIL INTERCONNECTIVITY

By

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Bachelor of Science in Economics

Wuhan University

2011

A thesis submitted in partial fulfillment of the requirements for the

Master of Science in Engineering

Civil and Environmental Engineering and Construction

Howard R. Hughes College of Engineering

The Graduate College

University of Nevada, Las Vegas

December 201

THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Tingting Yu

entitled

Developing Seamless Connections in the Urban Transit Network: A Look Toward High-Speed Rail Interconnectivity

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Engineering -- Civil and Environmental Engineering

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December 2014

Abstract

In the past, the studies in the U.S. on high speed rail have been on economic impact. Recently, there are a few studies on the multimodal connectivity at high speed rail stations. High speed rail stations are viewed as hubs that are connected by different modes of public transportation by which passengers are transported to their destinations. How and in which way these different modes are connected to high speed rail stations influence the ridership of high speed rail stations. As the development of high speed rail system in the U.S. has come to the stage for actual design and construction, providing guidelines on multimodal connectivity at high speed rail stations become highly needed.

The objective of this study was to quantify the multimodal connectivity of high speed rail stations. In this study, the multimodal connectivity is measured by the number of modes connected to high speed rail stations, the number of transportation facilities installed at HSR stations, the transfer time from the connecting modes to HSR stations, and the public transportation arrival time intervals. To achieve the objectives, data for different number of high speed rail stations in France, Spain, Japan and China were collected. With the data collected, the characteristics of the high speed rail stations in terms of connecting with other modes are identified. The relationship between ridership and the characteristics of multimodal connectivity of high speed rail stations were identified through developing regression models.

It was observed from the analysis that the multimodal connectivity at high speed rail stations in different countries present different profiles. For example, the high speed rail stations in China are connected with more bus lines than other countries. The bus lines connected to HSR stations in other countries are similar. Relatively, there are more bus stops/terminals provided in France. The transfer times in Japan and China are significantly longer than those in France and Spain. The average bus arrival interval in France is longest, more than double than that in China.

All the connectivity variables considered in this study influence the ridership in these four countries in different ways. Bus, subway, and regional railroad service influences ridership significantly. The number of bus services influences the ridership in three countries except France. The more bus services connected to high speed rail stations, the higher ridership for high speed rail is shown in these stations. Subway, light rail, traditional rail are modes of transportation with high capacity. Their connection to high speed rail station always implies high ridership for high speed rail. The number of facilities of connecting modes of transportation at HSR stations is also shown significant impacts on high speed rail ridership. For instance, the more bus and subway stops, and the more bicycle parking and taxi stands, the higher HSR ridership. Transfer time is identified to be significant influencing factor to HSR ridership: commuter rail and bicycle transfer time in France, and taxi transfer time for China. This study discusses the implications of these findings for the HSR stations proposed for California and Nevada. Pedestrian access is also discussed and recommended. Additional issues regarding transfer times in California's metropolitan areas are addressed.

Keywords: high-speed rail connectivity multimodal ridership

Acknowledgement

I want to offer sincerest gratitude to Dr. Hualiang Teng, Associate Professor in Transportation Engineering at the University of Nevada, Las Vegas, for his support throughout the years with his patience and knowledge, for all his contributions of suggestions, time, and funding to make my master experience productive, and for his encouragement and effort and without him this thesis would not have been completed or written.

I want to thank my thesis advisory committee guided me through all these days. Thank you to Dr. Mohamed Kaseko, Dr. Haroon Stephen, and Dr. Ashok Singh for being my major advisor. You have contributed immensely to my professional time at UNLV.

I wish to thank Mr. Tarik Toughrai, graduate student of school of engineering at the Ecole Nationale des Travaux Publics de I'Etat, Lyon, France, for doing the research of the country of France related to this study. I also thank Mr. Russell Ozawa, graduate student of University of Nevada, Las Vegas, for doing the research of Japan related to this study.

I want to thank Dr. Nobuaki Ohmori, Associate Professor of Department of Urban Engineering, The University of Tokyo, for providing the ridership data and some relevant information on the high speed rail stations in Japan. I want to thank Mr. Eduardo Romo, Presidente of Fundación Caminos de Hierro for providing the ridership data on the high speed rail stations in Spain. I also want to thank Dr. Binyi Hu, Associate Professor in the School of Computer Science at Beijing Jiaotong University, Beijing, China, for providing help on the research in China.

I want to thank MTI staff who provided additional editorial support.

I want to thank my parents for always supporting me.

I want to thank Xing for encouraging me to go all out for something we believe in.

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I. Introduction

Research on high-speed rail in the U.S. has typically been conducted from an economic perspective. Sands' report (1993) reviews the economic development fostered by high-speed rail systems in countries such as Japan and France. The reviews describe the economic impacts over time on the areas surrounding specific HSR stations in those countries. The report strongly recommends the development of a high-speed rail network in California for economic recovery in 1990s. Nuworsoo and Deakin (2009) and Murakami and Cervero (2010) focused their studies on the economic impact around high-speed rail stations, while Loukaitou-Sideris et al. (2012) looked into the impact of high-speed rail on cities in California.

A few recent studies have addressed multimodal connectivity at high-speed rail stations. Gregg and Begley (2011) focuses on providing adequate public transit connection to high-speed rail stations proposed for Orlando, Florida. That study discusses the many existing bus routes that represent HSR connection opportunities. A study by City of Fresno (2012) focuses on economic impact and urban revitalization. Neither study provides an extensive description of high-speed rail multimodal connectivity.

A high-speed rail station can be thought of as a hub that passengers can access through various modes of public transportation. From the hub, they will travel from their point of origin to their destination. The transportation modes connected to high-speed rail stations differ depending on their locations in the city and the land uses surrounding them. They also differ from the modes that connect to bus stops or subway stations because high-speed rail travel is different in nature from travel by bus or subway. Each HSR station, with its unique set of connection modes, facilities, and accessibility, offers travelers a different experience depending on variables such as arrival intervals, travel time, transfer time and convenience, parking facilities, etc. These variables influence ridership. If travelers perceive poor value in the services offered by high-speed rail and its connecting modes, they may use other modes of transportation to their destination. Even travelers who do ride high-speed rail may use connection modes other than public transportation. As America's high-speed rail system begins development, a set of fact-based guidelines for multimodal connectivity at high-speed rail stations is essential.

The objective of this study is to quantify the relationship of multimodal connectivity at high-speed rail stations to HSR ridership. Here, multimodal connectivity is defined as the number of modes connected to high-speed rail stations, the number of transportation facilities or terminals installed at HSR stations, the transfer time to and from the HSR stations via those modes, and arrival time intervals (passenger wait times). To achieve this objective, data were collected from various high-speed rail stations in France, Spain, Japan and China. Google maps were utilized to obtain aerial images of high-speed rail stations that showed the locations of connecting modes in relation to the station. Pictures of different transportation facilities connecting HSR stations were also collected. This information was then used to characterize the HSR stations in terms of their locations in a city and how other transit modes are connected to them. In addition, the number of services (e.g., bus routes) provided by each connecting mode, the number of facilities (e.g., bus stops and subway stations) for different modes, transfer time from different modes to high-speed rail stations, and scheduled service arrival intervals were collected from multiple sources. Ridership data were also collected for the HSR stations included in this study. With these data collected, the characteristics of the high-speed rail stations in terms of their connectivity to other modes were observed. The relationships between ridership and the characteristics of multimodal connectivity of high-speed rail stations were then identified through regression models. Implications of the findings on high-speed rail in California and Nevada are discussed in this study.

The thesis includes six chapters. The first chapter presents the background and problem statement. The second discusses the methodology used. Chapter III provides a brief literature review. Chapter IV describes the data collection. Chapters V discussed the analysis of the data. Chapter VI presents conclusions, implications of findings, and areas for further study.

II. Methodology

Factors that influence the ridership of high-speed rail were identified in this study in the process presented in Figure 1. After a literature review of relevant studies, data on transportation mode connectivity at high-speed rail stations were collected for four countries: France, Spain, Japan, and China. The collected data were analyzed separately. In the analysis, descriptive statistics were developed for the collected data. Linear regression models were calibrated based on the data from which the influencing factors on ridership were identified.

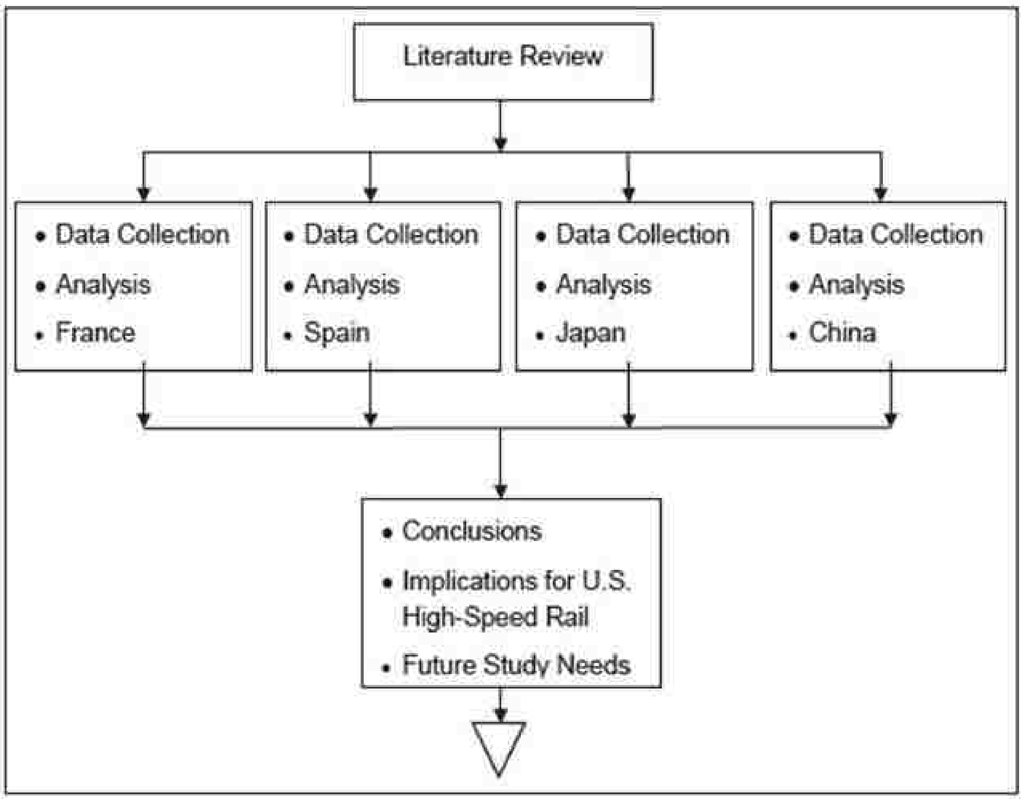


Figure 1 Flowchart of the Study

The interconnectivity data collected in this study include:

Number of public transportation services, i.e., routes/lines available for different modes:

• Number of bus services (lines, routes)

• Number of subway lines

• Number of tramway lines

• Number of light-rail lines

Number of facilities for public and private transportation:

• Number of bus stops

• Number of light-rail or tramway entrances

• Number of car rental facilities

• Number of parking lots, including drop-off, short-term or long-term parking spaces

• Number of taxi space

• Number of bicycle parking lots

Service interval in peak periods

Transfer time

Ridership for high-speed rail stations

The data sources differed for each country.

Transfer time for each mode is defined as the time required for passengers to traverse the distance between the drop-off points of their initial mode of transportation to their destination, i.e., the boarding platform. Note that HSR passengers typically plan to be at the station half an hour before their train's departure time, which is not considered in this study. Transfer time is calculated by dividing that distance by an average walking velocity of 4/3 ms^{-1}. Delays encountered at obstacles such as stoplights are not taken into account in the calculation. An additional 30 seconds is added if the traveler must take an escalator or an elevator. The destination "platform" is defined as the platform located in the middle of all available boarding platforms for that rail line.

Ridership data were analyzed by presenting the descriptive statistics and plotting the relationship between ridership and the influencing factors. The ridership data are modeled using the linear regression model:

$$y_i = \beta_0 + \beta_1 x_{i1} + \cdots + \beta_p x_{ip} + \varepsilon_i \qquad (1)$$

In which, $\beta_0 \ldots, \beta_p$ are the unknown partial regression coefficients. y_i denotes ridership; x_i represents influencing factors; ε_i is the error term that captures all other factors influencing ridership. This error term is assumed to be normally distributed.

The partial regression coefficients in equation (1) are estimated using ordinary least-squares technique. The fit of the regression model can be measured by using the sample coefficient of determination, which gives the proportion or percentage of the total variation in ridership, explained jointly by the characteristics of different modes for passengers accessing high-speed rail stations. It is given as:

$$R^2 = \frac{SST - SSE}{SST} \quad (2)$$

In which, SST is the total sum of squares given as:

$$SST = \sum_i^n (y\,i - \bar{y})^2 \quad (3)$$

SSE is the error sum of squares given as:

$$SSE = \sum_{i=1}^n (yi - \hat{y})^2 \quad (4)$$

Testing hypotheses about the insignificance of a population parameter at a given significant level uses a *t* test. The test of the influence of any population parameter uses an individual partial regression coefficient and can be conducted using a *t* statistic based on the regression coefficients and their standard errors as:

$$t\hat{\beta}j = \hat{\beta}j \Big/ se(\hat{\beta}j) \quad (5)$$

The coefficient is considered significant if the value in equation (5) is greater than the critical value determined from the level of significance and the number of degrees of freedom. For this study, a 5% level of significance is used.

III. Literature Review

Multimodal Connectivity

Mbatta (2008) conducted a study on developing and evaluating the criteria for transit stations with a focus on multimodal connectivity. In that study, the authors studied the paths that young, senior, and mobility-challenged passengers can follow from point of arrival at a transit station (either bus or rail) to their seats in a transit vehicle. The study established minimum design and evaluation criteria for public transit stations, with a special focus on seamless movement of passengers between transportation modes. Their proposed guidelines included a recommendation that transit stops not be located on the far side of a road that passengers must cross in order to access a given transit station. They presented layouts of transit stations showing the relative, recommended locations of key facilities such as park-and-ride, kiss-and-ride, and bus stops.

Isekil et al. (2007), discussed: (1) what criteria passengers use to evaluate transit stops and stations, and (2) what factors influence their evaluations of transit stops and stations based on five top criteria: 1) access, 2) connection and reliability, 3) information, 4) amenities, and 5) security and safety. In this study, connection is defined as the distance and time it takes to make connections. Five transfer facility types were considered, from the simple form, such as a stop serving a single transit mode, to a city center, grade-separated, multimodal, multilevel bus or rail transfer facility. A survey was conducted in the Los Angeles area at selected transit stops or stations classified as one of five transfer facility types. The survey found that improvements in service quality (i.e., good connection and reliability) and personal safety and security are much more important to transit users than physical conditions of transit stops and stations.

The MTC Transit Connectivity study conducted in 2006 indicated that, for transit hubs, the keys to success include reliable service, three-minute maximum transfer time, effective way finding, and seamless fare systems. They examined each of these four factors at the hubs in the San Francisco Bay area and provided recommendations for improvements.

Report TOD 202: Station Area Planning - Reconnecting America (2008), identified eight TOD place types: (1) regional center, (2) urban center, (3) suburban center, (4) transit town center, (5) urban neighborhood, (6) transit neighborhood, (7) special-use-employment district, and (8) mixed-use corridor. Some of the proposed guidelines for station area planning relate to transit connectivity: (1) maximize ridership with transit-oriented development, (2) manage parking effectively (e.g., minimize parking to the extent possible and maximize access for pedestrians, bicyclists, and those who arrive at stations by bus or shuttle), (3) maximize neighborhood and station connectivity (e.g., the walkability of the streets surrounding a station has a significant impact on whether people will choose to walk and ride transit). With the information on TOD, attention was given to the availability of pedestrian and bicycle accommodations at high-speed rail stations. Attention was also given to the question of whether the amount of car parking space has any impact on the number of passengers who choose to arrive on foot or by bicycle.

Transit Ridership

Taylor and Fink (2003) provided a literature review of the studies on transit ridership. The ridership studies were classified into descriptive and causal approaches (see Figure 2). The descriptive approach focuses on traveler attitudes and perceptions, with travelers and operators as the unit of analysis, while the causal approach considers the environment: systems and behavior characteristics associated with ridership. The causal approach includes aggregate and disaggregate studies, in which aggregate studies use system operators as the unit of analysis, and the disaggregate studies focus on mode choice decision making of individual travelers. The factors that influence ridership are classified into internal and external. The internal factors include those that system operators control, such as fare and service level, while external factors are those that are exogenous to the system and managers, such as population and employment in service areas.

There is a different category of ridership model that focuses on transit stations. One example is the study by Chan and Miranda-Moreno (2013) in which trip production and attraction models at the station level for the metro network in Montreal, Quebec were developed. This study found that population density, average income, bus service connectivity, distance to the central station, and service frequency are linked to the number of trips started from an area during morning peak hours, while factors such as commercial and governmental land uses, bus connectivity, and transfer stations are associated with the number of trips ended in an area during morning peak hours. Cervero, et al. (2009) is another study that estimates ridership at the station/stop level. Their study includes three categories of variables: service attributes (frequency, vehicle brand, dedicated lane); location and neighborhood attributes (population and employment density, mixed land use measures, etc.); and bus stop/site attributes (bus shelter, bus bench, etc.). It was found that service frequency, intermodal connectivity, population and employment density are highly related to ridership at Bus Rapid Transit (BRT) stops.

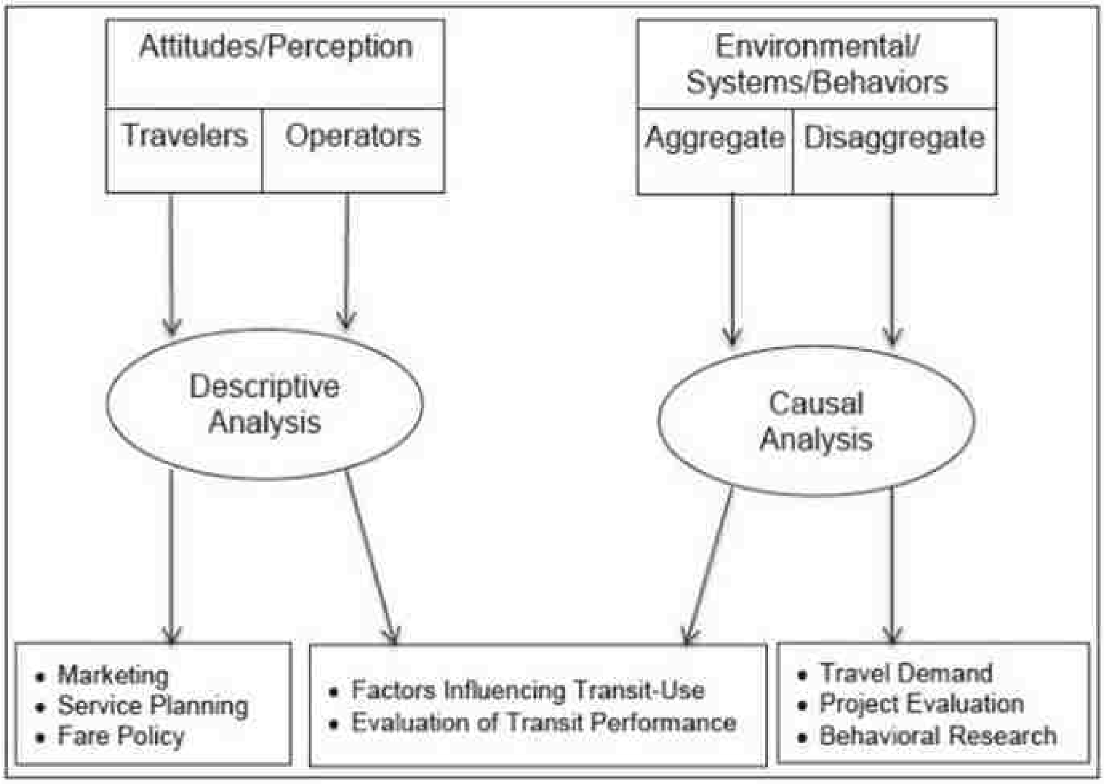


Figure 2 Categories of Ridership Studies (Taylor and Fink 2003)

High-Speed Rail Connectivity and Ridership

Only a few studies address multimodal connectivity at high-speed rail stations. Gregg and Begley's (2011) study focuses on providing adequate public transit connection to the high-speed rail stations proposed in Orlando, Florida. In this study, many bus routes are noted for their potential connectivity to the proposed high-speed rail stations. City of Fresno (2012) is another such study, focused exclusively on that city. It discusses a proposed high-speed rail station in the context of economic impact and urban revitalization. In these two studies, only the station itself was discussed; multimodal HSR connectivity was not addressed.

The economic impact of high-speed rail has been studied more frequently and more thoroughly. Sands (1993) is among the early studies on high-speed rail in California. It includes reviews of the economic development generated by the presence of high-speed rail in countries such as Japan and France. The reviews describe the economic impacts of certain stations on the surrounding areas over a period of time. Possible conclusions are suggested regarding high-speed rail development in California. Nuworsoo and Deakin (2009) and Murakami and Cervero (2010) focused their studies on the economic impact on areas surrounding high-speed rail stations, while Loukaitou-Sideris, et al. (2012) looked into the impact of high-speed rail on cities in California.

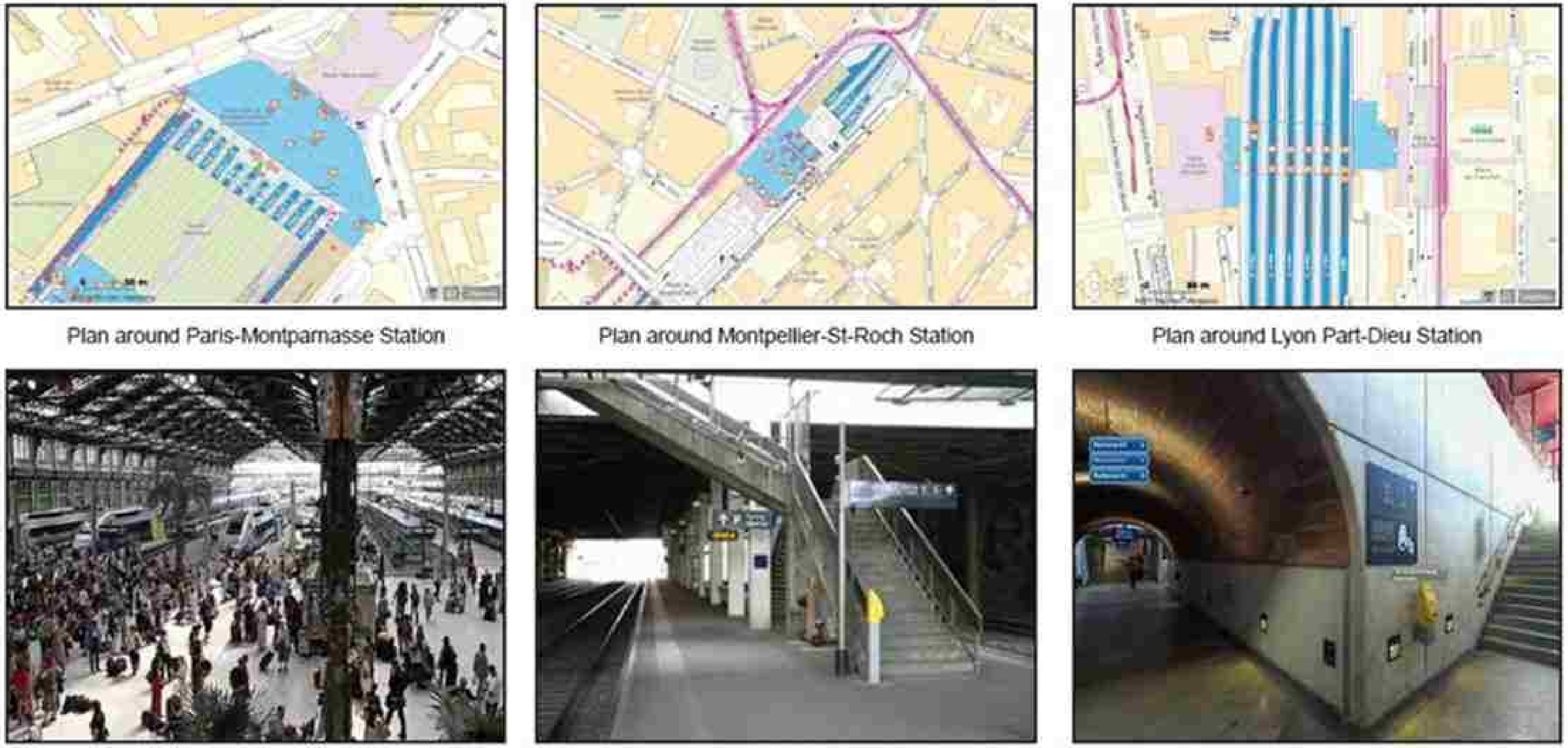
This study evaluates the relationship of multimodal connectivity at high-speed rail stations on ridership. Linear regression models were developed in which transit service, service facilities, transfer time and HSR service intervals are considered. These four groups of variables represent the multimodal connectivity at HSR stations. From the results of regression models, the aspects of multimodal connectivity at HSR are identified.

IV. Data Collection

High-speed rail stations are hubs that are accessed via different modes of public transportation and allow passengers to transfer from one mode to another. They are interfaces between different scales of territory: regional, national and international.

Characteristics of High-Speed Rail Stations

In general, there are three types of high-speed rail stations: terminal stations, bridge stations and underground stations (see Figure 3). Tracks of terminal stations end at the station. Trains must pull out of the stations in the direction opposite that from which they arrive. Platforms in these stations are on ground level, eliminating the need to take an escalator or an elevator. Some stations can be viewed as bridges, where the platforms are under the station. In these stations, passengers must use escalators or elevators to access platforms. Some high-speed rail stations are underground, where platforms are above stations. In these stations, passengers must use an escalator or an elevator to access the platforms.



Plan around Paris-Montparnasse Station | Plan around Montpellier-St-Roch Station | Plan around Lyon Part-Dieu Station

Platforms at Paris-Lyon Station | Access to the Platform in Angers-St-Laud | Underground HSR Station: Access to the Platform in Strasbourg Station

Terminal station	Bridge station	Underground station

Figure 3 Layout of High-Speed Rail Stations and Platforms

Data Collection - France

High-speed rail in France. The French high-speed rail system—official name: Train à Grande Vitesse but commonly known as "TVG"—began operations in 1981. Initially, it linked only two major cities: Paris and Lyon. It has since become a global network with a consistently growing ridership.

The TVG operates at an average speed of 200 km/h but certain lines, known as the LGV (Ligne a Grande Vitesse), can reach a maximum speed of 320 km/h. The French high-speed rail network was been built along old railway lines. Nine LGV lines are in service as of this writing:

• LGV Sud-Est: 409 km long, joining Paris and Lyon

• LGV Atlantique: 279 km long, serving the west and the southwest areas of the country

• LGV Nord: 333 km long, joining Paris to the Belgium border, via Lille

• LGV Interconnexion Est: 57 km long, divided into three parts connecting the LGVs Nord and Sud-Est

• LGV Rhône-Alpes: 115 km long, extending the LGV Sud-Est

• LGV Méditerranée: 250 km long, extending the LGV Rhône-Alpes to Marseille

• LGV Est Européenne: 300 km long, connecting Paris to the country's eastern regions, with an eventual goal of connecting Paris to Eastern Europe

• LGV Perpignan - Figueras: 44 km long, crossing the Spanish border to Figueras

• LGV Rhin-Rhône: 137 km long, running between Dijon and Mulhouse in eastern France

The network presents a radial structure with Paris at the center, a reflection of the organization of the French territory.

French Rail Network (RFF) owns and maintains the railway network, while the French National Railway Corporation (SNCF) operates it. These two companies are the primary financiers of the nation's HSR infrastructure. Financing is also provided by local authorities, who are in charge of the service at high-speed rail stations and connections to public transportation. Currently, the network includes more than 250 stations, including stations in Germany, Belgium, Spain, Great Britain, Italy, Luxembourg, Monaco, the Netherlands and Switzerland.

Figure 4 High-Speed Rail Network in France

Each station is unique in its design and architectural characteristics. Stations in major cities differ from those in small cities rural areas. Those in major cities are typically older stations that reflect the city's character. With their highly stylized architecture, they are widely regarded as city monuments. Figure 5 illustrates that they are located in densely populated areas at the heart of the city. Most stations on an LGV line outside of Paris are new construction with simple and modern design. These are typically located on the city's periphery (see Figure 6).

(a) Location of Gare de Paris-Est

(b) Gare de Paris-Est, built in 1849

Figure 5 High-Speed Rail Station in Dense Urban Area

The data for this study were collected for the 34 French high-speed rail stations, listed in Table 1. As shown in Figure 7, these 34 stations are located in diverse parts of the country, including major cities, outside of major cities and in rural areas. Seven are terminal stations:

Paris- Nord, Paris-Est, Paris-Montparnasse, Paris-Lyon, Lille-Flandres, Marseille-St-Charles and Tours. Five were built for the new LGVs: Avignon TGV, Aix-en-Provence TGV, Charles-de- Gaulle 2 TGV, Marne-la-Vallée Chessy and Lille-Europe.

All of the data collected in this study is taken from www.gares-en-mouvement.com/, which is the official website of the SNCF stations in France, the website passengers usually access for the schedules of public transportation and the trains, as well as the locations of the parking lots. High-speed rail data includes the number of services provided by the high-speed train in each station as well as its ridership. They are taken from SNCF sources.

(a) Location of Gare d'Aix-en-Provence TGV

(b) Gare d'Aix-en-Provence TGV, built on the LGV Méditerranée

Figure 6 High-Speed Rail Station in Rural France

Table 1 France: 34 High-Speed Rail Stations Studied

Stations	
1. Paris-Nord	18. Grenoble
2. Paris-Lyon	19. Metz-ville
3. Paris-Montparnasse	20. St-Roch
4. Paris-Est	21. Rouen-rive-droite
5. CDG2 TGV	22. Dijon-ville
6. Part-Dieu	23. Angers St-Laud
7. Perrache	24. Mans
8. Lille-Flandres	25. Toulon
9. Lille-Europe	26. Tours
10. Strasbourg	27. Avignon TGV
11. St-Charles	28. Colmar
12. Bordeaux St-Jean	29. Nîmes
13. Nantes	30. Mulhouse-ville
14. Toulouse-Matabiau	31. Marne-la-Vallée-Chessy
15. Nice-ville	32. Aix-en-Provence TGV
16. Nancy-ville	33. St-Pierre-des-Corps
17. Rennes	34. Lons-le-Saugnier

Modes connecting to high-speed rail stations. Bus remains one of the modes most widely used in public transportation. It can be operated either within an urban transportation system or as an interurban transportation system. Urban buses are managed by the municipalities or the federations of municipalities in France, and thus are connected to all of the stations included in this study except the Aix-en-Provence TGV station, which is not located in a city with an urban bus system.

Urban buses are usually highly efficient for city use because they can bypass typical urban congestion in dedicated bus lanes. Buses offer many routes that serve high-speed rail stations (see Table 2). Additionally, high-speed rail stations are also served by interurban bus systems. These interurban buses bring passengers from other cities of the region into the cities where high-speed rail stations are located. Their travel distance is longer than the travel distance of urban buses, and their speed is higher than urban buses. They are present in almost all the high-speed rail stations (Table 2). For each high-speed rail station, the number of routes is often larger than the number of urban bus routes. However, in large cities like Paris and Lyon, the urban buses are dominant.

Figure 7 Location of the 34 High-Speed Rail Stations Studied

Tramway is also a popular mode of public transportation in urban area. It has its own right-of-way on the surface of the road. This transit mode is not provided in all cities included in this study (see Table 2). Only the largest communes can often afford to have a tramway system. Among the 34 high-speed rail stations in this study, 15 are served with at least one tramway. Note that Paris does have a tramway system, which, however, is not connected to the four high-speed rail stations included in this study. It can be seen from Table 2 that the number of tramway routes is lower than that of bus routes. However, their ridership capacity is much larger.

Subway is a mode of public transportation usually seen in large cities. It has exclusive dedicated right-of-way, most times running underground. It carries masses of passengers. It is similar to a tramway in that only the larger cities can afford a subway system. Among the 34 high-speed rail stations studied, 12 are served by at least one line of subway. Five of them are also served by the tramway: Lille-Europe, Lille-Flandres, Lyon-Part-Dieu, Lyon-Perrache and Marseille-St-Charles. It can be observed from Table 2 that the number of subway routes serving each station is similar to that of tramway routes serving stations.

RER (RéseauxExpressRégional – RegionalExpressNetwork) is a mode of public transportation inside Paris that is similar to a subway, but with fewer stops and a higher ridership capacity. It is exclusively underground within the city of Paris. Outside Paris, where it operates on ground level, it serves as a commuter train for the suburbs around Paris. As shown in Figure 8, the RER system is composed of five lines (A, B, C, D and E). In this study, only the Ile-de-France region (Parisian region) has this mode of public transportation. The RER serves three of the four Parisian high-speed rail stations (Paris-Est, Paris-Lyon, Paris-Nord) and the high-speed rail station of Charles-Charles-de-Gaulle 2 TGV.

Taxi is an individual mode of public transportation. It is used when passengers wish to travel to high-speed rail stations with their luggage. All the high-speed rail stations in this study are connected with taxi service.

Despite the efforts made by society to limit the use of the car for environmental reasons, cars are still widely used in France, particularly for driving or being driven to a high-speed rail station. It is an individual mode of transportation that can be used in different ways:

A traveler can drive to the station and leave the car at a parking facility

A second party can drop off and pick up the traveler at the station

The traveler can rent a car

All three choices are accommodated at all high-speed rail stations in this study.

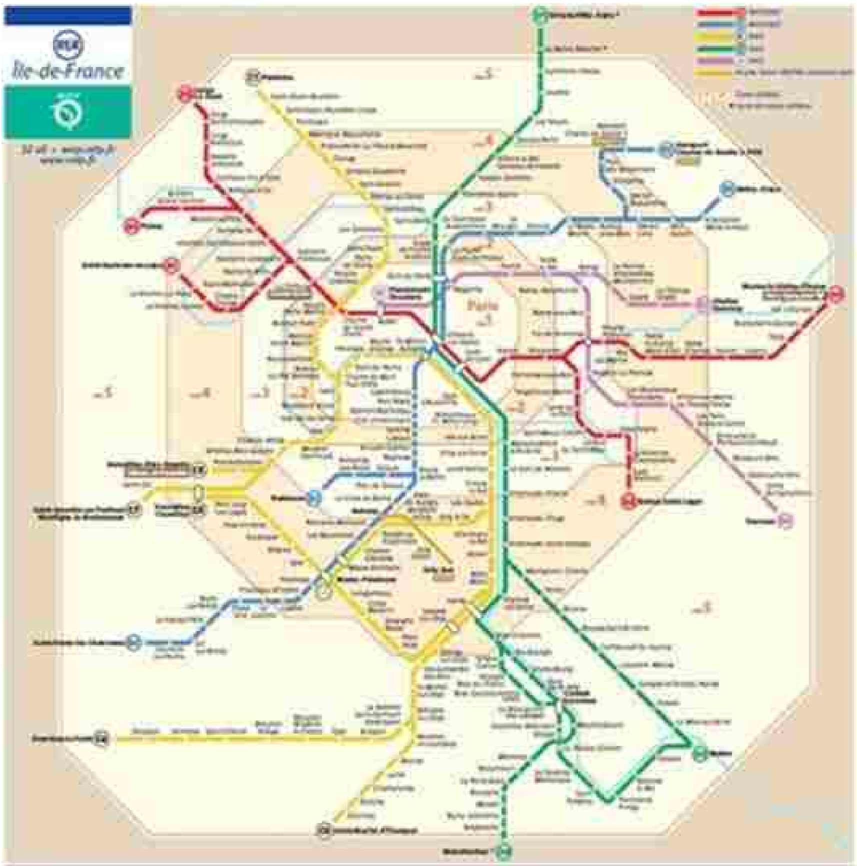


Figure 8 RER Network in the IIe-de-France Region

Passengers can also use the Motorail train, which carries the passenger's car along with the passenger, much like a ferry. Commuters can leave their cars in a parking lot, and the Motorail service will put them onto a train. Among the 34 high-speed rail stations included in this study, such a service is available at eight stations: Lyon-Perrache, Strasbourg, Marseille-Saint-Charles, Bordeaux-Saint-Jean, Nantes, Toulouse-Mat abiau, Niceville and Metz-Ville. Passengers can also share a car with another commuter heading for a high-speed rail station, given the rideshare program available for some stations, including Paris-Montparnasse, Lille-Flandres, Strasbourg, Nantes, Rennes and Grenoble. Finally, travelers may use a public car service system in which a fleet of cars may be shared by a group of people. Only two high-speed rail stations—Lyon-Part-Dieu and Montpellier-Saint-Roch—are equipped with such a system.

Table 2 Modes Connecting to High-Speed Rail Stations in France

Stations	Number of Urban Bus Routes	Number of Interurban Bus Routes	Number of Tramway Routes	Number of Subway Routes	Number of Routes of RER
Aix-en-Provence TGV		4			
Angers St-Laud	9	32	1		
Avignon TGV	1	9			
Bordeaux St-Jean	5	3	1		
CDG2 TGV	2	6		1	1
Colmar	16	11			
Dijon-ville	8	14			
Grenoble	2	24	2		
Le Mans	4	13	1		
Lille-Europe	3	4	2	2	
Lille-Flandres	9	4	2	2	
Lyon-Part-Dieu	12	5	2	1	
Lyon-Perrache	14	5	2	1	
Marseille-St-Charles	6	16	1	2	
Metz-ville	15	29			
Montpellier -St-Roch	7	9	2		
Mulhouse-ville	8	13	1		
Nancy-ville	8	26	1		
Nantes	4	19	1		
Nice-ville	9	4	1		
Nimes	12	24			
Paris-Est	10			3	1
Paris-Lyon	10	2		2	2
Paris-Montparnasse	8	2		4	
Paris-Nord	15			3	3
Rennes	7	22		1	
Rouen-rive-droite	4	2		3	
Strasbourg	2	6	5		
Toulouse-Matabiau	7	32		1	
Tours	21	12			
Average	8.21	12.57	1.67	2	1.75

Bicycles and motorcycles are individual modes of transportation that can be used to access high-speed rail stations. Bicycle travel is much appreciated in France because of its low environmental impact. Among the 30 stations included in this study, only one station—Charles-de-Gaulle 2 TGV—does not offer bicycle or motorcycle facilities. Thus, this high-speed rail station is difficult to reach for those who prefer these two modes of transportation. Bicycles can be a public or private mode. Out of the 34 HSR stations considered in this study, 20 possess a bicycle sharing system. They are: Paris-Nord, Paris-Lyon, Paris-Montparnasse, Paris-Est, Part-Dieu, Perrache, Lille-Flandres, Lille-Europe, Strasbourg, St-Charles, Bordeaux St-Jean, Nantes, Toulouse-Matabiau, Niceville, Nancy-Ville, Rennes, St-Roch, Rouen-rive-droite, Dijon-ville and Mulhouse-ville. To access high-speed rail stations by bicycles more quickly and safely, bicycle paths are often provided along primary routes to high-speed rail stations.

Facilities and connection to high-speed rail stations. Each mode of transportation requires unique facilities, including:

The most commonly used facility for buses are bus stops, which can consist of anything from a simple signpost to a shelter. The same bus stop can be shared by several bus lines. Where several bus lines share a bus stop, the stop can be expanded into a bus station, a larger infrastructure that may play the role of a multimodal station. These bus stations sometimes present as a building. They are widely used by interurban buses in France.

Bus stops and bus stations are usually located outside train stations. Bus passengers must walk a long way to reach high-speed rail platforms. Table 3 presents the number of bus stops, some of which are shared by urban and interurban buses at each high-speed rail station.

Like bus passengers, tram passengers bound for HSR stations board at tramway stops. As tramways are usually at ground level, passengers must cross streets to reach train platforms. The number of tramway stations is usually the same as the number of tramway lines because tramway lines rarely share stations. The high-speed rail station of Strasbourg, Lille-Flandres and Lille-Europe are exceptions because some tramway routes run underground, and passengers disembark at a level below the train station.

As their name implies, subways operate and deliver passengers below ground level.

Commuters can depart the subway at various points. Indeed, a single subway station can have exit points either inside or outside a high-speed rail station. Transferring to train platforms requires riding an escalator or elevator.

Like subways, the RER operates and stops underground while inside the city of Paris, where it serves three high-speed rail stations (Paris-Est, Paris-Lyon, Paris-Nord). It also stays underground at the CDG2 TGV station. Usually, passengers depart these stations at the same points as the subway exits and ride an elevator or escalator to reach train platforms.

Taxi stations are dedicated for use by taxis. They are located next to high-speed rail stations, often in front of the main entrance. Passengers may be required to cross streets to reach the station.

Regardless of the specific strategy used by car commuters (e.g., pick up, long-term parking, motorail), parking facilities are necessary. Depending on the station, the number of available spaces and the price of parking vary.

Parking may be underground, at ground level or elevated. In particularly dense urban areas, underground parking and elevated parking permit closer access to a station. Thus, some parking facilities require taking an escalator or an elevator to reach a high-speed rail platform. The exit of the parking lot may be located inside or outside the station. For ground level parking, passengers often must cross a street to reach the station.

Drop-off zones are essentially on-street parking. Like taxi stations, they are located very close to a station.

Passengers using bicycles and motorcycles can leave their vehicles in parking facilities reserved for them. Typically, there are numerous bicycle and motorcycle parking lots around high-speed rail stations. Again, however, travelers must cross streets to reach the station. At some stations, bicycles are provided by a public bicycle system. Sometimes bicycle parking is provided inside the rail station, leaving passengers very close to platforms.

In summary, high-speed rail stations offer various connecting modes, each with different transfer facilities. These facilities can be large in number and located in various places around high-speed rail stations.

Urban and interurban buses can share bus stops. They can also be grouped in bus stations that require larger facilities. This is not the case for high-speed rail stations located in big cities, such as Paris and Lyon, where bus stops group no more than two or three bus lines. Consequently, big stations located in densely populated areas have a greater number of these types of facilities.

Because tramway routes are more divergent than bus routes, tramway lines rarely share stations. On the other hand, underground subway station exits can be shared, even with the RER, one example being Parisian HSR stations where the RER is underground. For both RER and subways, the number of exits can be multiple and located inside or outside the station.

Each high-speed rail station offers between one and five taxi stations. The stations in Paris and Lyon offer larger numbers.

The number of automobile parking lots per station varies. The HSR stations of Paris and Lyon have the largest number of parking lots. The stations of Aix-en-Provence TGV and Avignon TGV, which are new and located in rural areas, also have a large number of parking lots. It should be noted that stations in large cities, such Paris and Lyon, have the largest number of parking lots for bicycles and motorcycles.

Figure 9 indicates that the connection facilities for public transportation modes carrying the largest number of passengers, such as tramway, subway or RER, are usually located closer to HSR stations than those for modes carrying fewer passengers, such as buses.

It can be seen from Figure 10 that bicycle and motorcycle parking are close to high-speed rail stations but generally scattered.

Figure 11 shows that drop-off zones and taxi stations are closer to the station than car parking lots.

Subway, RER and some parking lots have their exits located inside high-speed rail station. To transfer, people must take one or more escalators or elevators to reach their desired platforms. Placing exits inside stations permits faster and easier access to stations and conserves space around the station, which is desirable in densely populated areas. For the other modes, transfer locations can generally be placed in front of stations or within a few blocks. In that case, passengers must make their way through the station or cross streets.

This chapter assessed high-speed rail station connectivity in France as a function of the number and variety of transportation modes providing access and the availability of adequate and convenient transfer facilities at the station.

Table 3 Facilities for HSR Connection Modes in France

Stations	Number of Bus Stops	Number of Tramway Facilities	Number of Subway Station Exits	Number of RER Station Exits	Number of Taxi Stations	Number of Parking Lots and Drop-off Zones	Number of Bicycle or Motorcycle Parking Stations
Aix-en-Provence TGV	3				2	16	2
Angers St-Laud	9	1			1	8	8
Avignon TGV	3				2	16	1
Bordeaux St-Jean	8	1			3	9	13
CDG2 TGV	12		1	2	4	12	0
Colmar	13				3	7	4
Dijon-ville	10				1	7	2
Grenoble	9	2			2	16	4
Le Mans	8	1			2	10	5
Lille-Europe	4	1	1		1	8	6
Lille-Flandres	9	5	5		3	13	11
Lyon-Part-Dieu	11	2	3		5	17	17
Lyon-Perrache	10	2	1		1	16	9
Marseille-St-Charles	11	1	3		2	13	7
Metz-ville	11				1	10	5
Montpellier-St-Roch	6	2			3	13	8
Mulhouse-ville	15	1			2	3	8
Nancy-ville	5	1			2	10	17
Nantes	6	1			3	18	6
Nice-ville	6	1			2	12	11
Nimes	9				1	5	2
Paris-Est	13		3	1	1	5	6
Paris-Lyon	16		13	12	3	11	18
Paris-Montparnasse	14		2		5	17	15
Paris-Nord	10		6	4	4	7	31
Rennes	7		2		3	9	9
Rouen-rive-droite	8		3		1	6	4
Strasbourg	11	6			1	11	5
Toulouse-Matabiau	7		3		1	5	10
Tours	9				1	6	5
Average	9.10	1.87	3.54	4.75	2.20	10.53	8.59

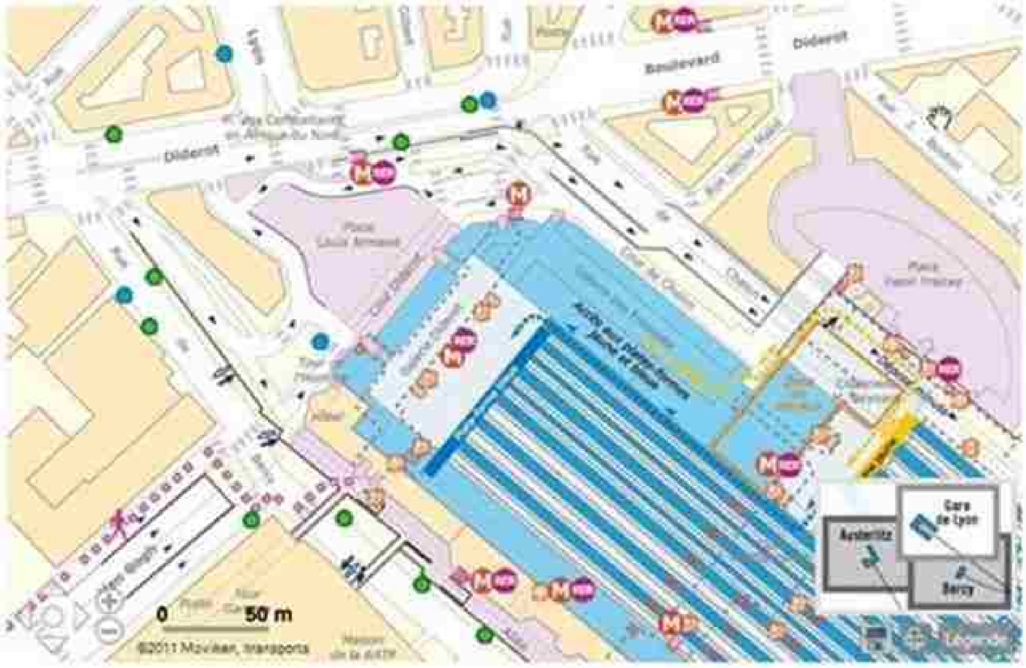


Figure 9 Bus Stop, Subway and RER Exits in Paris-Lyon Station

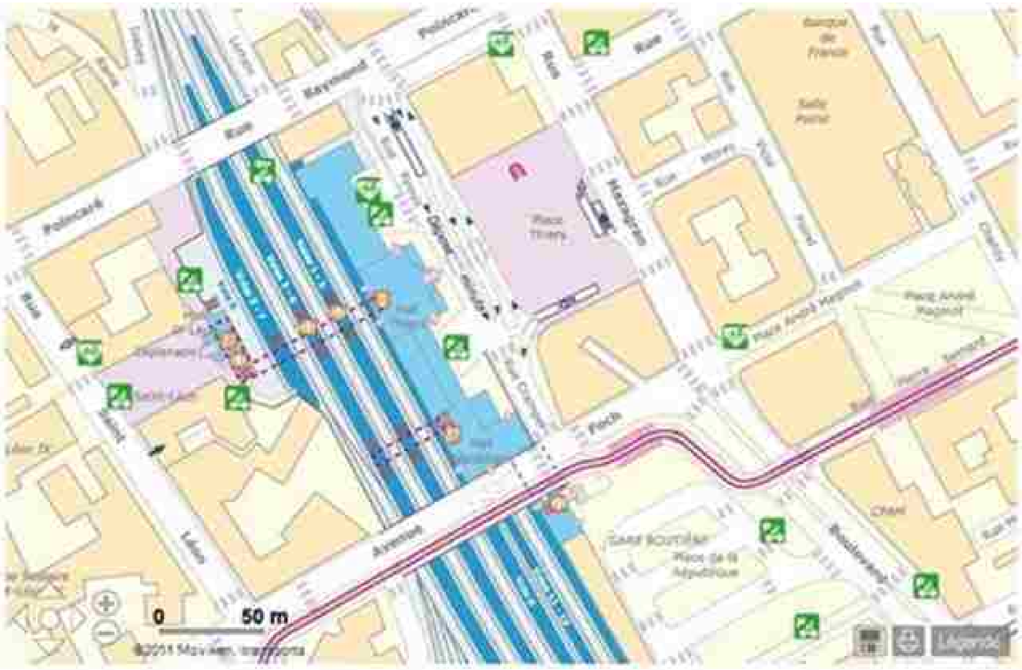


Figure 10 Bicycle and Motorcycle Parking at Nacy-ville Station

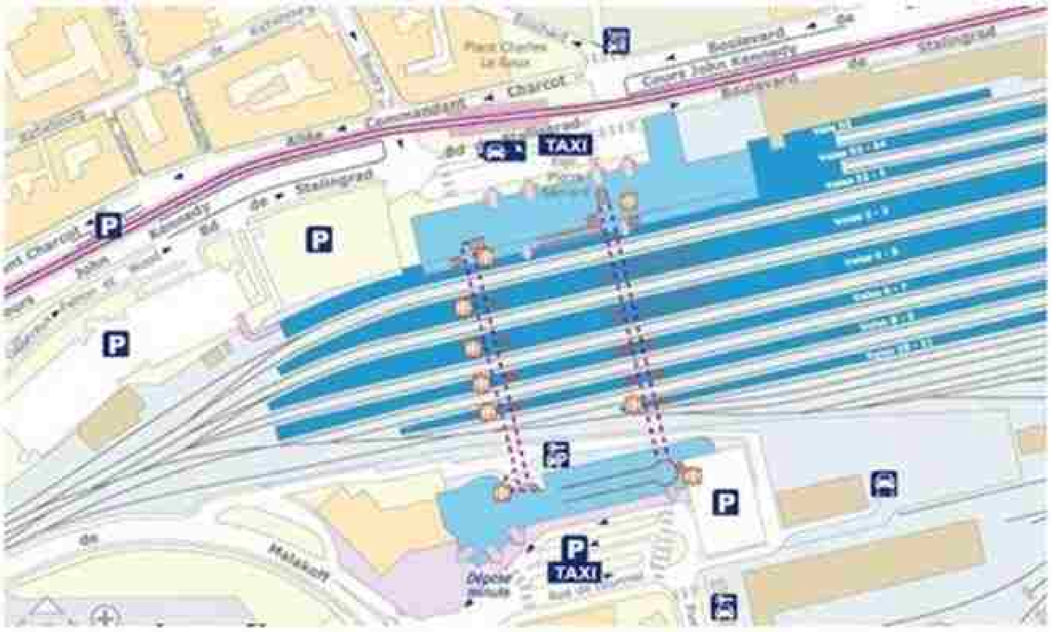


Figure 11 Taxi Stations and Car Parking Lots around Nantes Station

Depending on the station, these facilities may be closer to or further away from boarding platforms. They may be physically linked to platforms via escalator, elevator or tunnel. All of these parameters play a role in the calculation of the transfer time.

Data Collection - Spain

High-speed rail in Spain. Spanning 1,900 miles (3,100 km), Spain's high-speed rail system (See Figure 12) is the longest high-speed rail system in Europe. It can travel up to 193 mph (310 km/h)**.**

There are three types of operation lines within Spain's high-speed rail system: the newly built high-speed rail service (the AVE), the mid-distance high-speed rail system (the AVANT), and the mixed high-speed rail/conventional system (the ALVIA). Table 4 lists the lines currently in operation in Spain. These lines are shown in the map in Figure 12.

In this study, the data were collected for 16 high-speed rail stations in Spain, which are listed in Table 5.

Modes connecting to high-speed rail stations. Traveling by bus in Spain is usually far more affordable and faster than traveling by train. Many companies provide bus links from local routes between villages to fast intercity connections. Buses offer many routes that serve high-speed rail stations.

Figure 12 Map of High-Speed Rail in Spain

Table 4 Lines of High-Speed Rail in Spain

AVE	AVANT (mid-distance)	ALVIA (mixed high speed-conventional)
AVE Madrid–Seville via Ciudad Real, Puertollano, and Córdoba	Madrid–Ciudad Real-Puertollano	Madrid–Irún, via Valladolid, Burgos and San Sebastián
AVE Madrid–Barcelona via Guadalajara, Calatayud, Saragossa, Lleida and Tarragona	Madrid–Toledo	Madrid–Bilbao, via Valladolid and Burgos
AVE Barcelona–Seville via Saragossa and Córdoba	Málaga–Córdoba–Seville via Antequera and Puente Genil	Gijón–Alicante, via Valladolid and Madrid
AVE Barcelona–Málaga via Saragossa and Córdoba	Segovia–Madrid	Madrid–Logroño
AVE Madrid–Huesca via Guadalajara, Calatayud, and Saragossa	Calatayud–Saragossa	Barcelona–Irún, via Saragossa, Pamplona and San Sebastián
AVE Madrid–Valladolid via Segovia	Zaragoza–Huesca	Barcelona–Bilbao, via Saragossa and Logroño
AVE Madrid–Málaga via Ciudad Real, Puertollano, Córdoba, and Antequera	Barcelona–Lleida	Barcelona–Vigo, via Saragossa, Pamplona, Vitoria, Burgos, Palencia and Leon. With connection services to Gijón in Leon and to A Coruña in Monforte de Lemos Madrid–Huelva, via Madrid and Seville

Table 5 Spain: 16 High-Speed Rail Stations Studied

1. Barcelona- Sants	9. Ciudad Real
2. Madrid- Chamartin	10. Puertollano
3. Madrid-Puerta de Atocha	11. Cordoba
4. Valladolid	12. Sevilla
5. Segovia	13. Zaragoza
6. Toledoo	14. Lleida-pirineus
7. Valencia	15. Camp de Tarragona
8. Malaga	16. Ciudad Real

Only two cities in Spain employ metro systems: Madrid and Barcelona. The HSR system in Madrid is the sixth longest in the world. Note that Madrid is also approximately the 50th most populous metropolitan area in the world. The Madrid Metro is in operation every day from 6:00 a.m. until 1:30 a.m.

There is apparently little encouragement for biking in Spain. Barcelona, however, is an exception. In that city, cycling lanes have been implemented along main roads and several residential routes, making it possible for visitors to enjoy the city via bicycle. Years of highway improvement programs across the country have made cycling a much more appealing mode of travel and sightseeing than it was previously. In addition to commuter cycling, there are plenty of options for recreational biking, from mountain biking in the Pyrenees to distance riding along the coast. Still, drivers are not always supportive of bicycle traffic.

Taxi stands in Spain are typically located outside railway stations. In major cities, travelers can hail a taxi directly from the street, but in small towns, taxis are usually available only at taxi stands. A recent consumer survey found that the most expensive taxis were in Castellón, Murcia and Tarragona, and the least expensive in Almería, Cádiz and Santa Cruz de Tenerife. However, Spanish taxis are among the cheapest in Europe, which is evident from their use by the general public for everyday errands, such as shopping. Table 6 presents the data on the modes of public transportation available at high-speed rail stations in Spain.

Facilities and connection to high-speed rail stations. Local buses can take passengers just about anywhere, but most buses connecting villages and provincial towns are not geared to tourist needs. According to the Lonely Planet website, frequent weekday services drop off to a trickle Saturdays and Sundays. In the smaller towns, often there is only one daily pickup for travel between towns during the week, and none on Sunday. It is usually unnecessary to make reservations.

In most large towns and cities, buses leave from a single bus station. In smaller towns, they tend to operate from a set street or plaza, often unmarked. Locals know where to go.

Table 6 Modes Connecting to High-Speed Rail Stations in Spain

Station	Number of Bus routes	Number of Metro lines	Regional Bus lines	Suburban Bus lines	Suburban Railway lines
Barcelona-Sants	5	2	6	10	5
Madrid-Chamartin	3	1			
Madrid-Puerta de Atocha	33	1	8		
Valladolid					
Segovia	1				
Toledo	3				
Valencia	11				
Malaga	12				
Ciudad Real					
Puertollano					
Cordoba	6			30	
Sevilla	6				
Zaragoza	5			33	
Lleida-Pirineus				7	
Camp de Tarragona					
Figueres-Vilafant	5				
Average	8.18	1.33	7.00	20.00	5.00

Usually, tickets are purchased at a specific bar, although in some cases they may be purchased on the bus. Cities and provincial capitals all operate reasonable bus networks. Regular buses run from approximately 6:00 a.m. to shortly before midnight.

Metro terminals at high-speed rail stations in Spain often are located inside the station, significantly decreasing transfer time.

Bicyclists are often able to bring their bicycles with them on the train. All regional trains have space for bikes. Bikes are also permitted on most local area trains near big cities such as Madrid and Barcelona. On long-distance trains there are more restrictions. It is not known whether high-speed trains allow bikes on board. Table 7 lists the number of transportation facilities at high-speed rail stations in Spain.

Table 7 Facilities for HSR Connection Modes in Spain

Station	Bus stops	Metro stations	Regional Bus Stops	Suburban Bus Stops	Suburban Railway Stations	Taxi stands	Bicycle parking	Car parking
Barcelona-Sants	5	1	1	1	1	1	4	6
Madrid-Chamartin	3	1				1		4
Madrid-Puerta de Atocha	17	1				3	2	2
Valladolid						1	3	7
Segovia	1					1	1	2
Toledo	1					1	1	3
Valencia	1	1				1		2
Malaga	3					1	1	2
Ciudad Real	2					1	2	5
Puertollano						1	1	7
Cordoba	5			1		1	1	1
Sevilla	4					1	1	7
Zaragoza	8			1		2	2	1
Lleida-Pirineus				1		1	1	4
Camp de Tarragona						1	1	4
Figueres-Vilafant	2					1		1
Average	4.33	1.00	1.00	1.00	1.00	1.19	1.62	3.63

Data Collection - Japan

High-speed rail in Japan. Japan was the first country in the world to develop high-speed railway technology. High-speed rail in Japan, also known as Shinkansen, began operations in 1964 and has continued to grow and evolve ever since. Reaching maximum operating speeds of approximately 320 km/h, it is an enormously popular for long-distance travel and commuting.

Currently, there are 100 high-speed rail stations in Japan that are in operation, with future stations planned. The Shinkansen essentially runs the length of Japan, forming a nearly contiguous line. The Shinkansen is broken into six main lines, as well as two mini-Shinkansen lines (upgraded narrow gauge railway lines to standard railway lines for Shinkansen use).

The main Shinkansen lines include (see Figure 13):

Tokaido Shinkansen: Begins in Tokyo; ends in Shin-Osaka. (Track length: 515.4 km).

Sanyo Shinkansen: Begins in Shin-Osaka; ends in Hakata. (Track length: 553.7 km).

Tohoku Shinkansen: Begins in Tokyo; ends in Shin-Aomori. (Track length: 674.9 km).

Jotetsu Shinkansen: Begins in Omiya; ends in Niigata. (Track length: 269.5 km).

Nagano Shinkansen: Begins in Takasaki; ends in Nagano. (Track length: 117.4 km).

Kyushu Shinkansen: Begins in Hakata; ends in Kagoshima-Chuo. (Track length: 256.8 km).

Mini-Shinkansen lines include:

Yamagata Shinkansen: Begins in Fukushima; ends in Shinjo. (Track length: 148.6 km).

Akita Shinkansen: Begins in Morioka; ends in Akita. (Track length: 127.3 km).

The data collection for this study includes 37 high-speed rail stations in Japan (see Table 8). To ensure diversity, the stations were selected randomly from among those that had maintained ridership records.

As shown in Figure 14, the 37 stations are located in different parts of the country, spanning almost the entire length of the network. (It should be noted that none of the stations on the Kyushu Shinkansen line were chosen due to a lack of data from this new line.) The stations are located in major metropolitan areas, as well as outside of major cities, in small towns and in rural areas.

As part of the data collection, other modes of transportation were identified at each high speed rail station that connected to that station. The other transportation modes identified for this study include: buses, taxis, railways, cars, bicycles

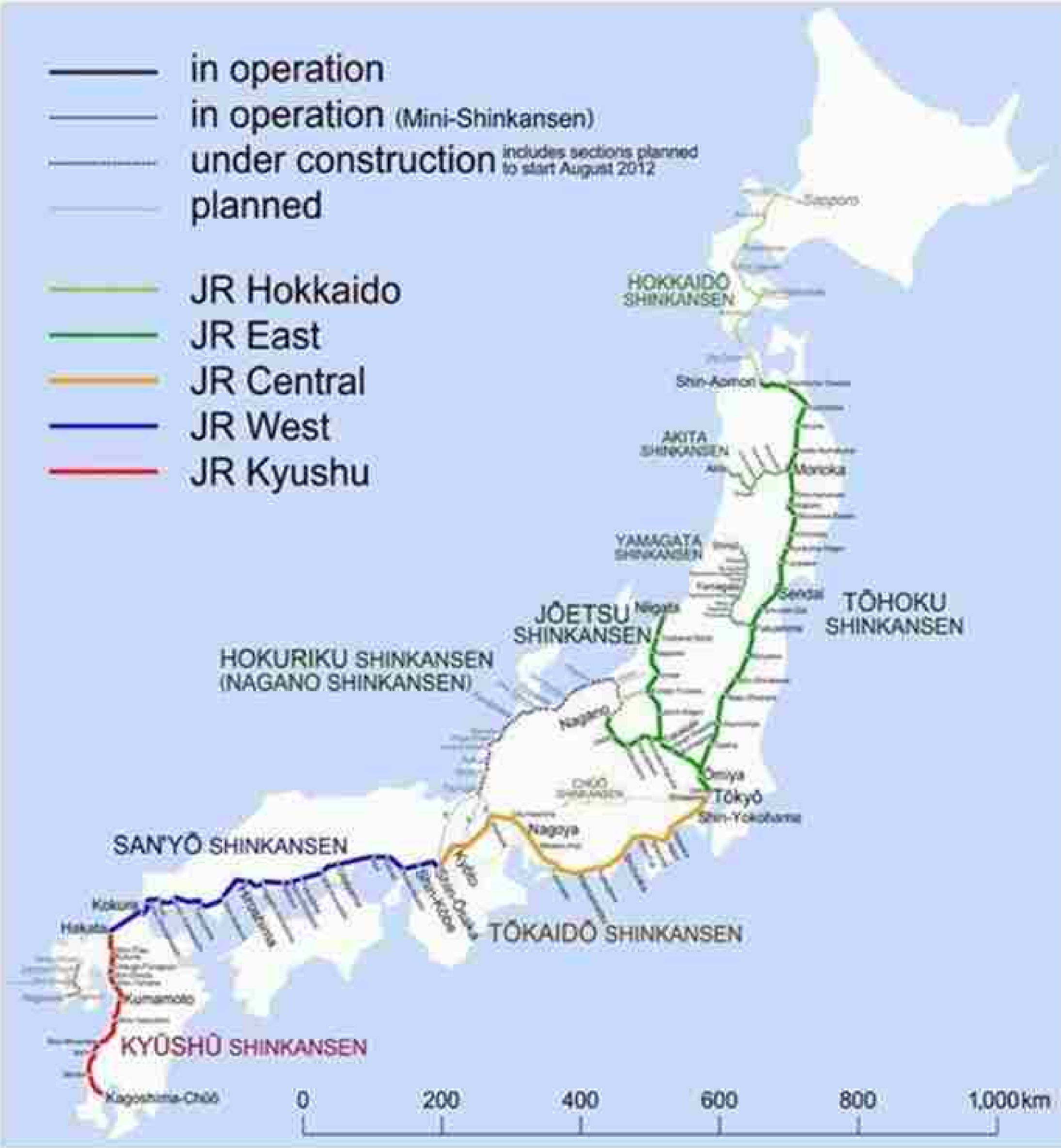


Figure 13 High-Speed Rail Network in Japan

The interconnectivity of these transportation modes was used in the data analysis to determine how they affect the ridership numbers for each particular station. With the help of Dr. Nobuaki Ohmori from The University of Tokyo, and online data, the ridership numbers for each high speed rail station in this study was found and used for the data analysis.

Table 8 Japan: 37 High-Speed Rail Stations Studied

	Stations		
1	Tokyo (東京)	20	Sendai (仙台)
2	Shin-Yokohama (新横浜)	21	Fukushima (福島)
3	Mishima (三島)	22	Oyama (小山)
4	Shizuoka (静岡)	23	Omiya (大宮)
5	Hamamatsu (浜松)	24	Akita (秋田)
6	Nagoya (名古屋)	25	Kakunodate (角館)
7	Kyoto (京都)	26	Shinjo (新庄)
8	Shin-Osaka (新大阪)	27	Murayama (村山)
9	Shin-Kobe ((新神戸)	28	Yamagata (山形)
10	Okayama (岡山)	29	Niigata (新潟)
11	Shin-Onomichi (新尾道)	30	Nagaoka (長岡)
12	Hiroshima (広島)	31	Jomo-Kogen (上毛高原)
13	Shin-Yamaguchi (新山口)	32	Takasaki (高崎)
14	Kokura (小倉)	33	Honjo-Waseda (本庄早稲田)
15	Shin-Aomori (新青森)	34	Kumagaya (熊谷)
16	Hachinohe (八戸)	35	Nagano (長野)
17	Morioka (盛岡)	36	Sakudaira (佐久平)
18	Kitakami (北上)	37	Annaka-Haruna (安中榛名)
19	Furukawa (古川)		

The data related to interconnectivity collected in this study include:

The approximate transfer times for each transportation mode to the Shinkansen platform

The number of bus stops

The number of taxi stands

The number of railway facilities (includes local rail, light rail, metro, and subway)

The number of car parking lots whether it is drop-off, short-term or long-term parking spaces

The number of bicycle parking lots

The numbers of services offered by each mode of urban public transportation (Bus and Railway only)

Modes connecting to high-speed rail stations. Each Shinkansen station offers multimodal connectivity to local destinations as well as to other Japanese cities.

Figure 14 Location of 37 High-Speed Rail Stations in Japan

Buses are one of the more popular modes of transportation in Japan, and all cities offer local and intercity service. Local buses provide transportation within city limits, while highway buses allow travel on the expressways and link cities to other cities, or cities to tourist destinations. Travel times can vary depending on traffic or accidents, but for the most part Japan's buses are punctual.

Taxis are widely available in Japan and provide door-to-door service. Taxis are an expensive alternative to public transportation, but they often are the only way to get around once trains and buses stop operating for the day. One advantage of taxi transportation is that taxi drop-off locations are immediately adjacent to high-speed rail stations, making the transfer times shorter.

In smaller cities or rural areas in a Japan, public transportation tends to be less convenient, increasing the importance of taxi service as an alternative.

Railways are the most efficient and convenient way to travel and commute in metropolitan cities that offer this service. Tokyo, for example, boasts one of the largest and most intricate railway networks in Japan, making rail one of the most popular modes of public transportation.

Railway transportation is also offered between cities, but the Shinkansen trains are more feasible and economical for this purpose. While Japan's rail service is not only extensive, it is also considered to be a very reliable source of public transportation. The Japanese pride themselves on the punctuality of their railways and the predictably accurate arrivals, departures and travel times (notwithstanding natural events, such as poor weather or earthquakes). Larger metropolitan areas tend to have a higher number of railway services compared with the smaller cities.

In large metropolitan areas such as Tokyo and Osaka, some people do not own a car or have a driver's license; they rely primarily on public transportation. However, in smaller cities or rural areas where public transportation is inconvenient or less frequent, people do rely on cars for mobility. All Shinkansen stations in Japan provide some type of car-related amenity, whether it is car parking, car rentals or passenger drop-off areas for cars.

Bicycles are widely used in Japan, both in large metropolitan areas and in small rural towns. They are the most sustainable mode of transportation and can be the most efficient way to travel or commute short distances, especially in densely populated urban areas. Bicyclists are expected to use streets and not sidewalks unless otherwise indicated by signage (See Table 9).

Various connection modes are offered at Shinkansen stations. Stations located in larger metropolitan areas offer more varieties, such as railways, buses and taxis because the transportation infrastructure is more complex and must accommodate a larger population.

In 2000, a commuting survey with approximately 4000 participants was conducted in Japan. While the study was not representative for the entire country, it provided a broad outlook on the relative popularity of various commuting modes. As seen in Figure 15, rail was the mode of choice for commuters, followed by car, bicycle and bus.

Table 9 Modes Connecting to High-Speed Rail Stations in Japan

HSR Station / (City)	Bus	Taxi	Railway	Car Parking	Bike Parking
Tokyo (Tokyo)	22	–	9	–	–
Shin-Yokohama (Yokohama)	7	–	2	–	–
Mishima (Mishima)	6	–	2	–	–
Shizuoka (Shizuoka)	6	–	1	–	–
Hamamatsu (Hamamatsu)	6	–	1	–	–
Nagoya (Nagoya)	7	–	6	–	–
Kyoto (Kyoto)	8	–	5	–	–
Shin-Osaka (Osaka)	14	–	3	–	–
Shin-Kobe (Kobe)	16	–	2	–	–
Okayama (Okayama)	12	–	5	–	–
Shin-Onomichi (Onomichi)	38	–	0	–	–
Hiroshima (Hiroshima)	38	–	5	–	–
Shin-Yamaguchi (Yamaguchi)	5	–	3	–	–
Kokura (Kitakyushu)	10	–	3	–	–
Shin-Aomori (Aomori)	6	–	1	–	–
Hachinohe (Hachinohe)	6	–	2	–	–
Morioka (Morioka)	3	–	5	–	–
Kitakami (Kitakami)	3	–	2	–	–
Furukawa (Osaki)	6	–	1	–	–
Sendai (Sendai (Miyagi))	6	–	6	–	–
Fukushima (Fukushima)	4	–	4	–	–
Oyama (Oyama)	2	–	4	–	–
Omiya (Saitama)	13	–	8	–	–
Akita (Akita)	3	–	3	–	–
Kakunodate (Senboku)	3	–	2	–	–
Shinjo (Shinjo)	6	–	3	–	–
Murayama (Murayama)	6	–	1	–	–
Yamagata (Yamagata)	6	–	3	–	–
Niigata (Niigata)	5	–	3	–	–
Nagaoka (Nagaoka)	5	–	2	–	–
Jomo-Kogen (Minakami)	8	–	0	–	–
Takasaki (Takasaki)	8	–	7	–	–
Honjo-Waseda (Honjo)	13	–	0	–	–
Kumagaya (Kumagaya)	13	–	2	–	–
Nagano (Nagano)	10	–	5	–	–
Sakudaira (Saku)	10	–	1	–	–
Annaka-Haruna (Annaka)	8	–	0	–	–
Average	9.41		3.39		

Facilities and connection to high-speed rail stations. Each mode of transportation connecting to Japan’s high-speed rail stations has unique facilities.

Bus facilities at a Shinkansen station may range from a simple bus stop to a full bus terminal (See Figure 16). Shinkansen stations located in larger metropolitan areas most likely have bus terminals to accommodate higher ridership, while Shinkansen stations in smaller cities have a few bus stops located near the entrances/exits of the station.

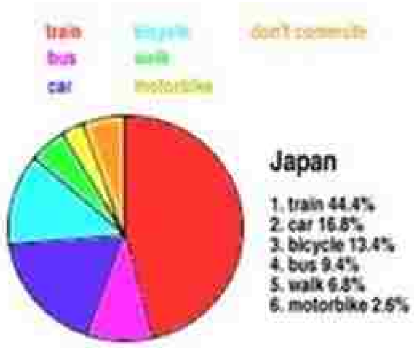


Figure 15 Commuting Mode Preferences in Japan

Bus stops and bus terminals are usually located on the outside of the Shinkansen stations.

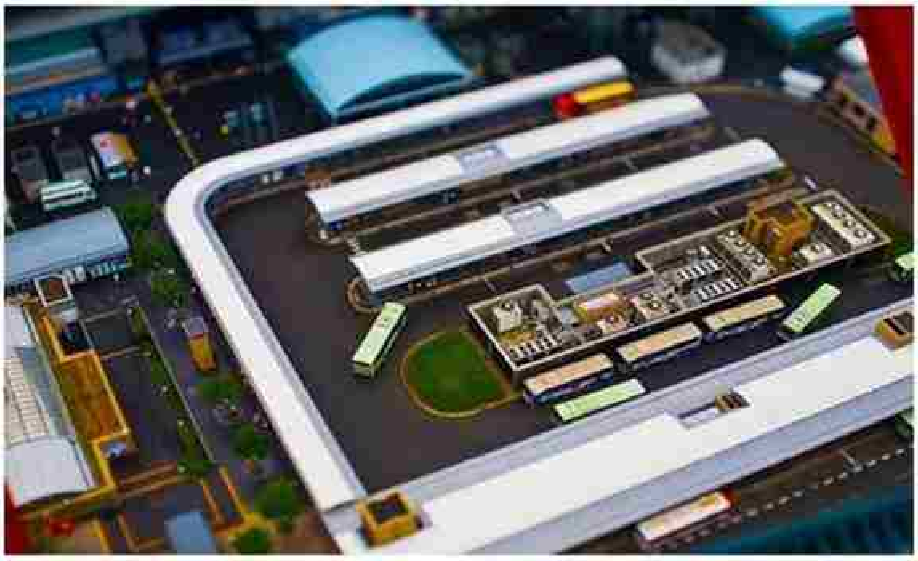


Figure 16 Bus Terminal at Kyoto Station (Aerial View)

Passengers typically need to walk from the drop-off point to the boarding platform. This may require crossing streets and traversing plazas or even department stores. Stations in larger cities offer correspondingly more and larger facilities, while the facilities at smaller cities are fewer and smaller.

Taxi stands are usually designated in specific areas near station entrances/exits. Transfer from taxi to trains typically requires walking from the taxi stand to the station platform. At most stations, taxis line up near taxi stands, so they are readily available.

Railway stations are usually located in the same facility as the HSR station. Local rails may be adjacent to the Shinkansen trains or sometimes below them. Subways are located underground. Transfer between local railways to Shinkansen trains requires passengers to walk from the railway platform to the Shinkansen platform. This may include using an escalator or elevator, as well as passing through ticketed gates. Large metropolitan cities typically have more railway platforms than smaller cities.

While cars are not the favored source of transportation in Japan, they are nonetheless widely used. The decision whether to use a car usually depends on the type of city. In larger metropolitan areas, car use is lower, while they are used more frequently in smaller rural areas of necessity because public transportation alternatives are fewer and less convenient.

Car parking is available at all Shinkansen stations, but fees vary by city. Parking at urban stations can be very expensive, while small towns and rural areas may charge no fee at all. Parking facilities at Shinkansen stations may include parking lots near the station or garages located in the train facility. While parking lots are usually on ground level, parking garages may include several stories above or below ground. Parking facilities usually require passengers to walk to the train platforms and typically involve crossing streets and/or using an escalator or elevator. Table 10 shows the approximate number of car parking lots at each Shinkansen station examined for this study. It should be noted that some parking lots/garages for large cities may not be included due to lack of information available online.

All Shinkansen stations in Japan provide designated areas for bicycle parking. While some stations may have bike parking lots, other parking facilities may be on sidewalks adjacent to station entrances. Transferring from a bike to a train usually requires walking from the bike parking area to the Shinkansen platform. Bike parking lots are typically on ground level, but some may be in garages or even underground. Table 10 shows the number of bicycle parking facilities at each station examined for this study. It should be noted that most bicycle parking information in Japan is not readily available on the internet, and the figures in Table 10 were approximated for use in this study.

While bicycle use is very popular in Japan, the parking situation for bicycles at some of the larger metropolitan stations has become a problem. Designated bike parking is located in most Shinkansen stations; however, many bicyclists park wherever convenient near the station, causing hazardous conditions for pedestrians and surrounding businesses. Recently, the Tokyo Metropolitan Government banned bicycle parking outside of designated bicycle parking areas, and there are plans to increase the number of bicycle parking facilities around the station.

High-speed rail stations in Japan accommodate different modes of transportation, with facilities for each. Large cities will usually have a greater number of facilities, while the smaller cities have fewer. The popularity of each mode usually depends on the location of the high-speed rail station. While railways are more popular in large metropolitan areas, smaller cities may see higher use of buses or cars. Since the majority of high-speed rail stations have similar layouts, passengers can easily locate their preferred transportation mode. High-speed rail stations also have ample signage to indicate the location of transit terminals and parking. Japan has a very efficient public transportation network, especially within metropolitan areas and between large cities. Japanese public transportation is characterized by its punctuality, reliability, frequent service and popularity. The number and type of facilities at each HSR station are generally influenced by ridership.

Table 10 Facilities for HSR Connections Modes in Japan

HSR Station / (City)	Bus	Taxi	Railway	Car Parking	Bike Parking
Tokyo (Tokyo)	32	11	20	10	2
Shin-Yokohama (Yokohama)	8	6	4	5	3
Mishima (Mishima)	12	12	4	7	2
Shizuoka (Shizuoka)	21	12	4	6	2
Hamamatsu (Hamamatsu)	19	15	4	7	3
Nagoya (Nagoya)	22	15	18	4	2
Kyoto (Kyoto)	42	22	21	6	2
Shin-Osaka (Osaka)	6	7	10	5	15
Shin-Kobe (Kobe)	6	8	3	4	2
Okayama (Okayama)	20	10	7	6	2
Shin-Onomichi (Onomichi)	5	4	0	6	2
Hiroshima (Hiroshima)	22	17	12	6	2
Shin-Yamaguchi (Yamaguchi)	8	6	8	3	2
Kokura (Kitakyushu)	5	10	10	8	2
Shin-Aomori (Aomori)	10	6	2	3	2
Hachinohe (Hachinohe)	6	8	5	8	2
Morioka (Morioka)	24	6	10	4	2
Kitakami (Kitakami)	10	8	4	6	2
Furukawa (Osaki)	7	4	2	7	2
Sendai (Sendai (Miyagi))	36	14	10	8	4
Fukushima (Fukushima)	17	10	6	9	2
Oyama (Oyama)	5	6	8	6	2
Omiya (Saitama)	12	12	17	6	4
Akita (Akita)	18	7	8	6	2
Kakunodate (Senboku)	2	2	3	1	1
Shinjo (Shinjo)	6	6	4	4	2
Murayama (Murayama)	2	2	2	2	2
Yamagata (Yamagata)	8	8	5	6	4
Niigata (Niigata)	28	10	7	6	4
Nagaoka (Nagaoka)	22	4	5	5	2
Jomo-Kogen (Minakami)	2	2	0	2	2
Takasaki (Takasaki)	14	6	8	6	4
Honjo-Waseda (Honjo)	2	4	0	5	2
Kumagaya (Kumagaya)	9	6	6	10	4
Nagano (Nagano)	13	9	9	4	4
Sakudaira (Saku)	3	7	1	6	2
Annaka-Haruna (Annaka)	1	1	0	4	1
Average	13.11	8.19	7.48	5.59	2.73

Data Collection - China

High-speed rail in China. Despite its relatively late entry into high-speed rail relative to countries such as Japan and France, China boasts the world's longest high-speed rail network, with approximately 5,800 miles of rail as of December 2012. In the mid-1990s, trains in China traveled at a top speed of about 37 mph. Today, China's high-speed railcars travel at an average speed in excess of 124 mph.

Daily ridership of high-speed rail services in China has grown from 237,000 in 2007 to 796,000 in 2010. China's high-speed rail network includes three types of lines: upgraded conventional railways, newly built high-speed passenger-designated lines (PDLs) and the world's first high-speed commercial magnetic levitation (maglev) line. The country is enjoying a high-speed rail building boom in response to funding from the government's economic stimulus program. The network is expanding rapidly, and the total network length is expected to reach 25,000 miles within the next 20 years (see Figure 17).

Figure 17 National High-Speed Rail Grid

The centerpiece of the expansion of conventional rail into high-speed rail is a new national rail grid overlain onto the existing railway network. According to China's "Mid-to-Long-Term Railway Network Plan," as revised in 2008, this grid is composed of eight high-speed rail corridors: four running north and south, and the other four running east and west. Together, these corridors cover 12,000 km (see Figure 17). Most of the new lines, known as passenger-designated lines (PDL), follow the routes of existing trunk lines and are designated for passenger travel only. Several sections of the national high-speed railway networks were built to link cities that had no pre-existing rail connections. Those sections will carry a mix of passengers and freight. The speed of high-speed trains on PDLs can reach approximately 300–350 km/h. This national grid project was planned for completion by 2020. Due to influx of economic plan stimulus funds, many lines now project considerably earlier completion dates.

The above-mentioned railway network plan, also notes that the government plans to expand the railway network in western China and to fill gaps in the networks of eastern and central China. Some of these new railways are being designed to accommodate speeds of 200~250 km/h for both passengers and freight. These railways are also considered high-speed rail, although they are not part of the national PDL grid or intercity high-speed rail.

In this study, data for 17 stations in China were collected. These stations are primarily along the east-west high-speed line from Xi'an to Zhengzhou in the center of China. These stations are listed in Table 11. Some data for other major high-speed rail stations, such as Beijing South, were also collected. Because ridership data cannot be made available for these stations, they were not included in this study.

Table 11 China: 17 High-Speed Rail Stations Studied

1	Zhengzhou East	10	Mianchi South
2	Luoyang Longmen	11	Anyang
3	Xi'an North	12	Shangqiu
4	Sanmenxia South	13	Xinxiang
5	Weinan North	14	Xinxiang East
6	Huashan North	15	Xuchang
7	Anyang East	16	Xuchang East
8	Kaifeng	17	Zhengzhou
9	Lingbao West		

Modes connecting to high-speed rail stations. Buses operate either within a city or between cities. They remain widely used as the major mode of public transportation, especially in the less-developed cities in China. To effectively use the capacity of buses, many cities adopt bus-only lanes.

Table 12 lists the number of bus routes in urban areas and the number of suburban bus routes for the stations included in this study.

Bus rapid transit has been successfully adopted in China. Many high-speed rail stations have a connection with BRT.

Due to China's extraordinarily large urban population, many Chinese cities offer subway service. In major cities, most subways connect to high-speed rail stations. However, most of the 17 stations included in this study are not located in major cities, and only one has a subway connection.

Taxis are commonly used by passengers traveling with luggage. As such, all high-speed rail stations provide taxi connections. Passenger loading and unloading is allowed at station entrances.

Passengers arriving by car may park in short-term or long-term parking facilities or be dropped off and picked up at convenient areas designated for this purpose. Alternatively, rental cars are available. These facilities and services are available at all stations considered in this study.

Despite China's efforts to reduce pollution and its appreciation for vehicles with a low environmental impact, such as motorcycles and bicycles—especially public bicycles—neither of these transportation modes is well accommodated at HSR stations in China. Among the 17 stations included in this study, only a few provide bicycle or motorcycle facilities.

Facilities and connection to high-speed rail stations. Bus is one of the most popular urban transportation modes in China, especially in less-developed cities where there are no subways. In some newly built high-speed rail stations in China, passengers may transfer to suburban buses without leaving the station.

Bus stops consisting of a stop or shelter are the most commonly used facilities for BRT at HSR stations. Several buses can share BRT bus stops. If many bus lines use a bus stop jointly, the stop can be transformed into a bus terminal that acts as a multimodal station.

In addition to the 17 stations included in the data analysis for this study, connectivity data for some of the major high-speed rail stations in China were also collected; they were not included in the analysis, however, due to a lack of available ridership data. Many of these provide nearby bicycle and motorcycle parking lots. Typically, passengers must cross squares and/or streets to traverse from these lots to the station.

Table 12 Modes Connecting to High-Speed Rail Stations in China

	Number of Bus Lines	Number of BRT lines	Number of Suburban Bus Lines	Number of Subway Lines
Zhengzhou East	8.00	1.00	14.00	
Luoyang Longmen	8.00			
Xi'an North	4.00			1.00
Sanmenxia South				
Weinan North	2.00			
Huashan North	4.00			
Anyang East	1.00			
Kaifeng	19.00		1.00	
Lingbao West				
Mianchi South				
Anyang	23.00			
Shangqiu	6.00			
Xinxiang	39.00			
Xinxiang East	3.00			
Xuchang	20.00			
Xuchang East	4.00			
Zhengzhou	80.00	2.00	1.00	
Average	15.79	1.50	5.33	1.00

Subway access points are located both inside and outside of HSR stations. Escalators or elevators are used to transfer passengers from the subway stop to the HSR station.

Taxi stations are dedicated to taxi vehicles. These stations are typically located directly outside HSR stations, often by the main entrance. However, a common inconvenience for taxi commuters is the travel distance between taxi stations and platforms.

Automobile parking lots are underground, at ground level or on elevated levels. In particularly dense urban areas, underground and elevated parking facilities allow more direct access to stations. However, in such cases, escalators or elevators are necessary for passengers to move from one facility to another. For ground-level parking, passengers typically must cross a street to reach the station. Drop-off zones, in this study, are not considered as parking. However, like taxi stands, these zones are located very close to the station. Table 13 lists the number of BRT stops, bicycle and motorcycle parking lots, subway stations, taxi stands and car parking facilities at the stations included in this study.

Table 13 Facilities for HSR Connection Modes in China

	Number of Bus Stops	Number of BRT Stops	Number of Subway Stations	Number of Suburban Bus Stops	Number of Car Parks	Number of Taxi Stands	Number of Bike Stands
Zhengzhou East	1.00	1.00		1.00	2.00	2.00	
Luoyang Longmen	4.00				1.00	1.00	
Xi'an North	1.00		1.00		4.00	1.00	
Sanmenxia South					4.00	1.00	
Weinan North	5.00					1.00	
Huashan North					5.00	1.00	
Anyang East	1.00				1.00	1.00	
Kaifeng	10.00			1.00	1.00	1.00	
Lingbao West					1.00	1.00	
Mianchi South					2.00	1.00	
Anyang	4.00				4.00	1.00	
Shangqiu	1.00				2.00	1.00	
Xinxiang	10.00				4.00	1.00	
Xinxiang East	3.00					1.00	
Xuchang	10.00				1.00	1.00	
Xuchang East	1.00					1.00	
Zhengzhou	9.00	2.00		2.00	8.00	2.00	
Average	4.62	1.50	1.00	1.33	2.86	1.12	0.00

V. Data Analysis

Data analysis - France

The data collected in this study were analyzed using a linear regression model. The descriptive statistics of the data are listed in Table 14. It is seen that the passengers arriving by taxi have the lowest transfer time: 141.9 seconds, or a little more than 2 minutes. The RER has the longest transfer time at 206.3 seconds, more than 3 minutes.

Among the four modes of travel not under passenger control, RER had the longest interval between regular trains arriving during peak periods, followed by buses. Subway trains had the shortest interval. Buses consistently offered more connecting routes. With regard to facilities, each HSR station in France provided an average of 10 car parking lots, 8.6 bus stops, 8.1 bike parking lots, 4 RER stations, 3.5 subway stations, 2.1 taxi rental services and 1.9 tramway stations.

Table 14 Descriptive Statistics of Transfer Time

	RER	Subway	Tramway	Bus	Bike	Car	Taxi
Transfer Time	206.30	170.40	203.50	199.80	173.10	188.00	131.90
Schedule	13.50	2.80	6.20	29.50			
No. of Services	1.60	2.00	1.70	7.80			
No. of Facilities	4.00	3.50	1.90	8.60	8.10	10.00	2.10

Relating the connectivity of multiple modes of transportation at HSR stations to ridership, Figure 18 shows that bus services number more than other modes, and this may not have a substantial correlation to high ridership. From Figure 19 it can be seen that there are many car parking facilities, bus stops and bike parking facilities at an HSR station. However, a high number of facilities may not be directly associated with high HSR ridership. Figure 20 shows that bus service intervals during peak period vary significantly, while the arrival intervals of other modes are shorter. The relationship between service intervals and ridership is not clear. From Figure 21, it cannot be determined which mode has a longer transfer time, nor the relationship of transfer time to ridership.

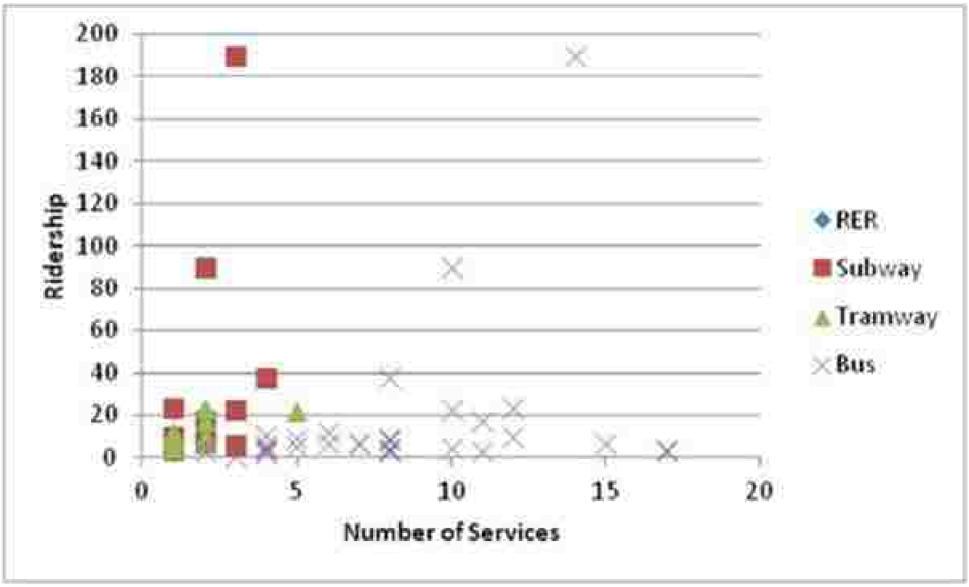


Figure 18 Ridership vs. Number of Service

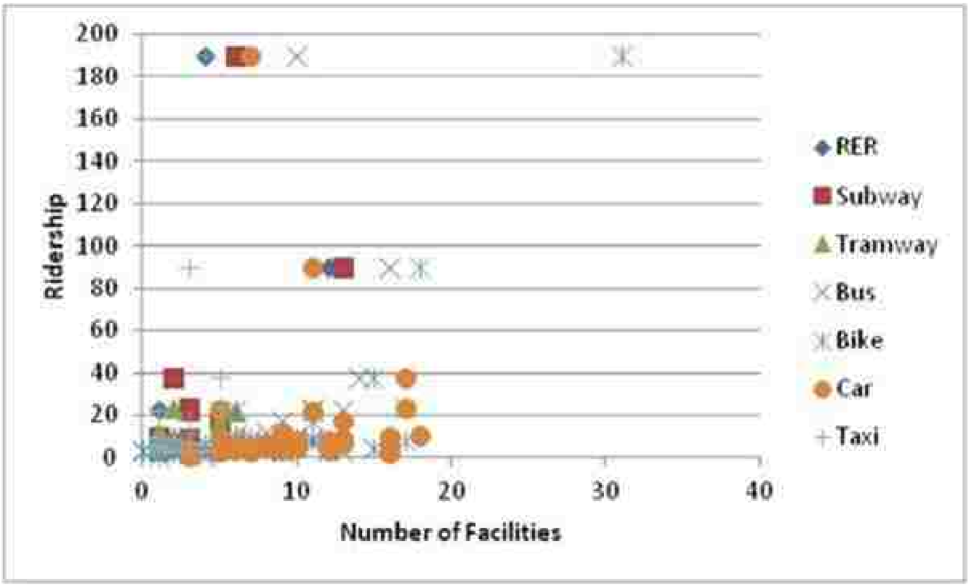


Figure 19 Ridership vs. Number of Facilities

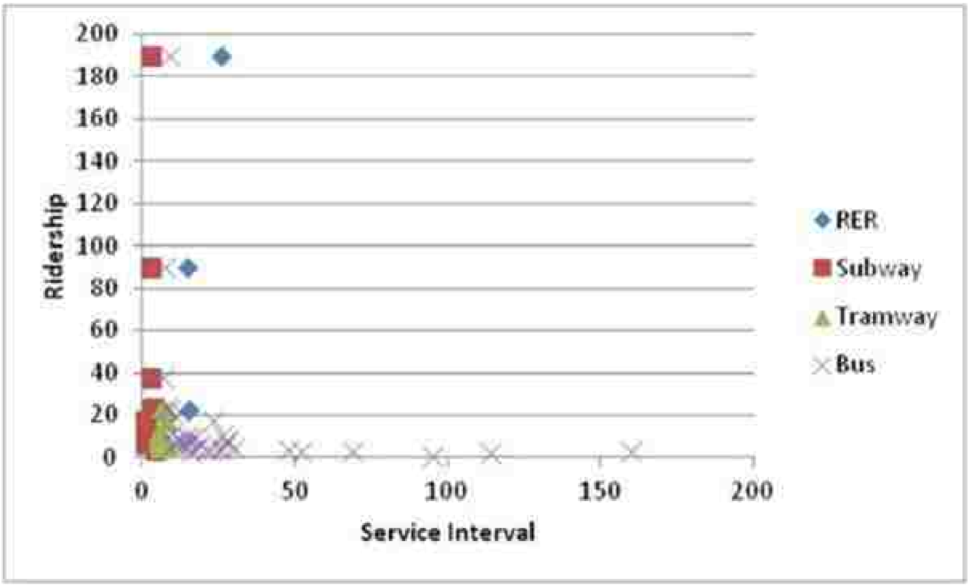


Figure 20 Ridership vs. Service Interval

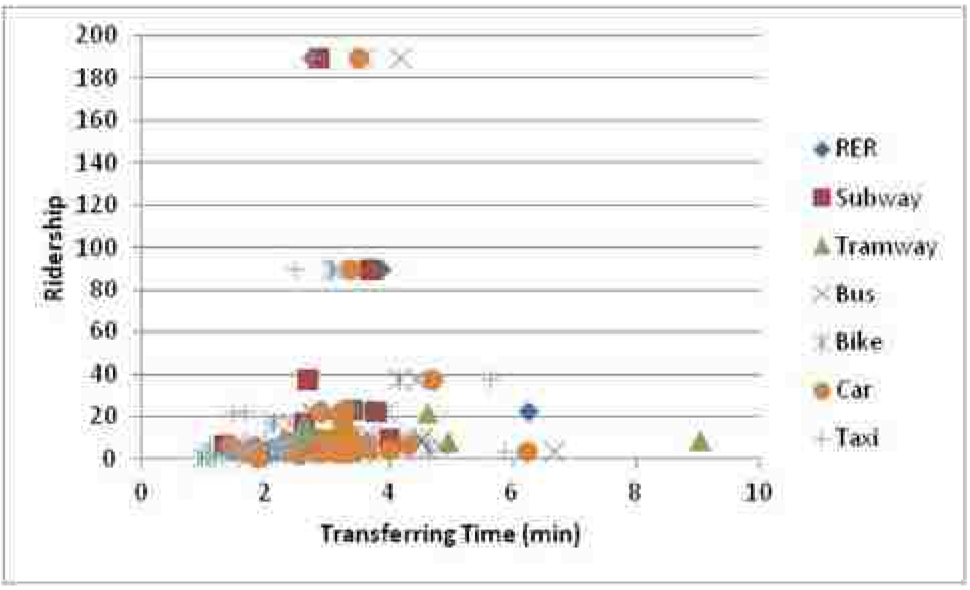


Figure 21 Ridership vs. Transfer Time

These data are analyzed using a linear regression model to identify the relationship between them and ridership. Table 27 in the Appendix provides the correlation coefficients for these variables. It was found that these four sets of variables are highly correlated: transfer time, schedule, number of service and number of facilities, as highlighted in yellow in Table 27. In the modeling, only one set of these four groups of variables was used. Table 15 shows the result from the regression models.

Table 15 indicates that the transfer time for RER and bikes is significant. The transfer time for other modes is not significant, which implies that the improvement on the transfer time for these five modes may not noticeably increase ridership. Their coefficients are negative, implying that the decrease in transfer time for RER and bikes would increase ridership significantly, thus the effort in increasing ridership should focus on the modes of RER and bikes.

Table 15 Linear Regression Results - 1

Independent Variable	Estimated Coefficient	Standard Error	t-Statistics
Constant	1.35907E+02	51.04971	2.66225
RER Transfer Time	-0.13361	2.54636E-02	-5.24718
Subway Transfer Time	9.84538E-03	1.43825E-02	0.68454
Tramway Transfer Time	-2.64553E-03	1.46650E-02	-0.1804
Bus Transfer Time	8.47004E-02	0.16407	0.51623
Bike Transfer Time	-0.15232	3.80119E-02	-4.0071
Car transfer Time	-0.14540	0.15921	-0.91331
Taxi Transfer Time	8.04043E-02	0.20022	0.40158
Bus Interval	-8.06694E-02	0.19274	-0.41855
No. of Bus Lines	0.88551	1.22324	0.72391
Existence of Airport	5.86729	9.18237	0.63897
No. of Bus Stops	-1.50352	1.98298	-0.75821
No. of Car Parks	-0.23952	1.44638	-0.1656
No. of Taxi Stands	9.87281	7.58208	1.30212
Number of Observations	34		
R-squared	0.82231		
Corrected R-squared	0.65507		
Sum of Squared Residuals	6.99818E+03		
Standard Error of the Regression	20.28935		
Durbin-Watson Statistics	1.61997		
Mean of Dependent Variable	16.37324		

Data Analysis - Spain

The relationship between the connectivity of multiple modes of transportation and ridership was investigated by first examining the charts representing their relationship. Figures 22, 23, 24 and 25 present the relationship between ridership and each of the four categories of variables representing connectivity. From Figure 22 it can be seen that there are more suburban bus lines connected to high-speed rail stations than metro and regular bus lines. However, their services were not associated with high-speed rail ridership. This could be due to the fact that most of the high-speed rail stations included in this study are located in small cities that are typically connected by suburban bus lines and do not generate significant ridership. Figure 23 shows that there are more accommodations for buses, cars and bicycles at Spain's HSR stations than for other modes of transportation. But the ridership associated with these three modes is necessarily high. It can be seen from Figure 24 that buses and metro services are available at relatively shorter intervals than those of suburban buses, and their frequent arrivals are associated with higher ridership. Figure 25 indicates that taxis, bicycles and buses usually have a shorter transfer time than other modes of transportation. But, again, their short transfer time may not necessarily be associated with high ridership.

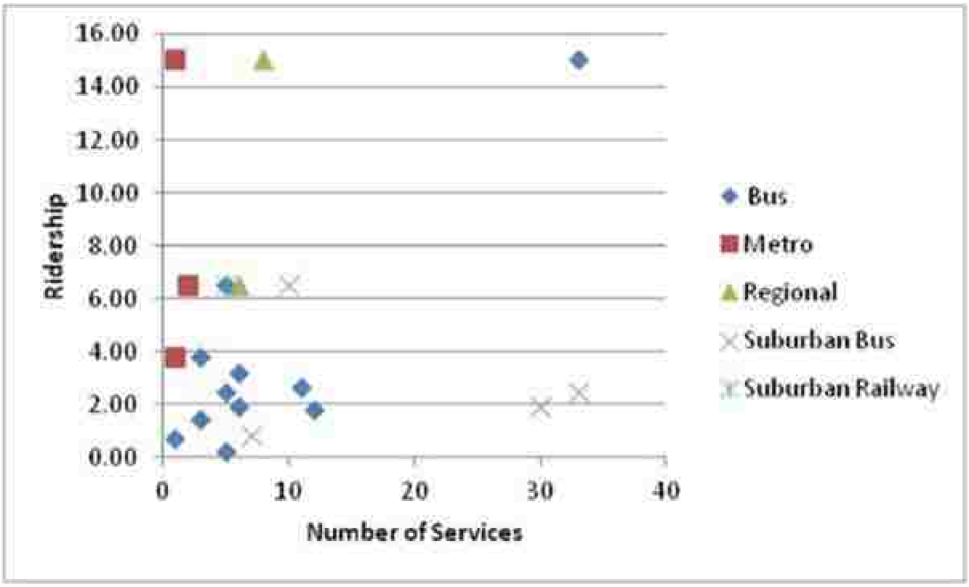


Figure 22 Ridership vs. Number of Services

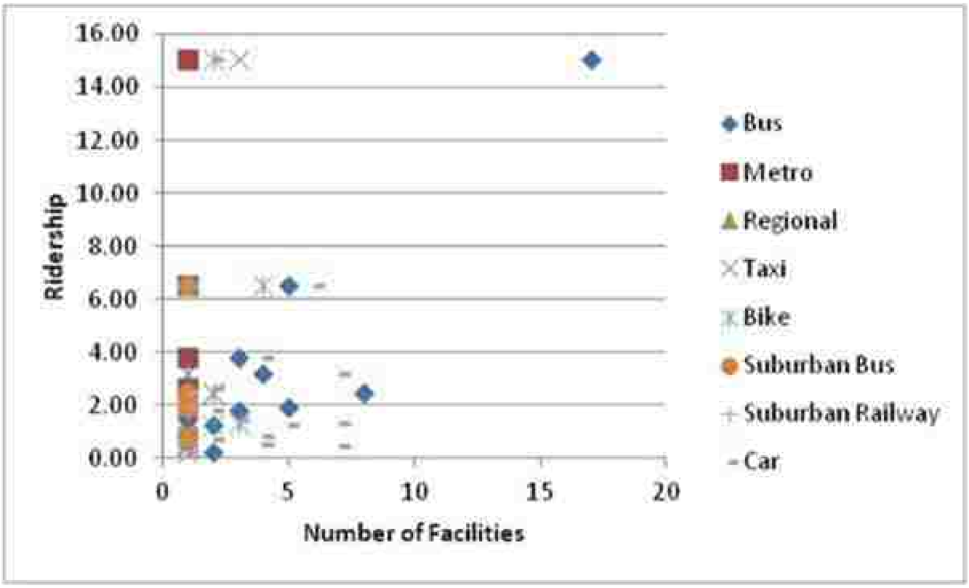


Figure 23 Ridership vs. Number of Facilities

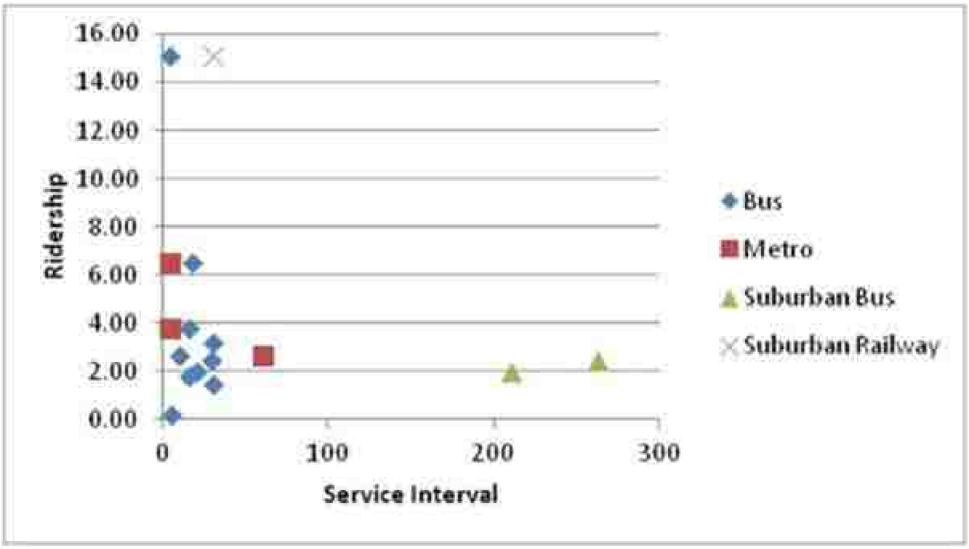


Figure 24 Ridership vs. Service Interval

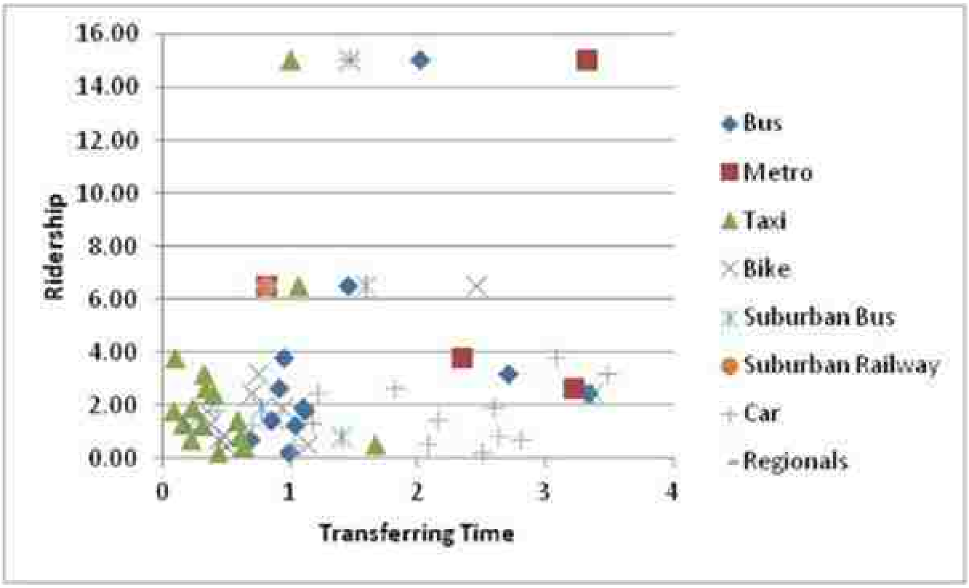


Figure 25 Ridership vs. Transfer Time

A linear regression model was developed to identify the connectivity factors that influence ridership at high-speed rail stations. The regression results are presented in Table 16. The data that have small sample sizes were removed from the regression analysis. The correlation coefficients of the variables included in the regression models are calculated and presented in Table 17. From Table 16 it can be seen that only two variables are significant: number of bus lines and number of bicycle parking stations. Both coefficients are positive, implying that ridership is higher for a high-speed rail station served by more bus routes and bicycle parking facilities.

Table 16Regression Results

	Coefficients	Standard Error	t-Stat	P-value
Intercept	-0.49913	1.6237	-3.074	0.018
No. of Bus Lines	0.4124	0.0531	7.7646	0.0001
No. of Bike Parks	1.4379	0.5243	2.7424	0.0288
No. of Car Parks	0.2765	0.2066	1.3381	0.2227
Bus Interval	0	0	0.6799	0.5184
Bus Transfer Time	0	0	-0.8538	0.4214
Taxi Transfer Time	1.1405	0.9397	1.2137	0.2642
Bike Transfer Time	0	0	1.23	0.2584
Car Transfer Time	0.9069	0.4618	1.9635	0.0903
R-Square	0.941526886			
Adjusted R-Square	0.874700469			
Observations	16			

Table 17 Correlation Coefficients

	Ridership	No.of Bus Lines	No.of Bike Parks	No.of Car Parks	Bus Interval	Bus Transfer Time	Taxi Transfer Time	Bike Transfer Time	Car Transfer Time
Ridership	1.00								
No. of Bus Lines	0.87	1.00							
No. of Bike Parks	0.35	0.04	1.00						
No. of Car Parks	-0.08	-0.38	0.41	1.00					
Bus Interval	-0.42	-0.53	0.14	0.44	1.00				
Bus Transfer Time	-0.32	-0.41	0.10	0.50	0.75	1.00			
Taxi Transfer Time	0.29	0.13	0.26	0.13	0.17	0.36	1.00		
Bike Transfer Time	-0.07	0.04	-0.60	-0.29	-0.37	-0.28	-0.26	1.00	
Car Transfer Time	-0.14	-0.15	-0.57	-0.11	-0.12	-0.09	-0.12	0.32	1.00

Data Analysis - Japan

The data collected in this study were analyzed using a correlation test and a linear regression model. Table 18 shows the descriptive statistics of the data found for this study. The values in Table 18 represent averages of the 37 stations used for this study. Regarding to the location of high-speed rail station platforms to the different transportation modes, the shortest transfer time was for taxi service, with an average transfer time of approximately 317 seconds (a little over five minutes). The highest average transfer time was for cars, with an average time of 397 seconds (a little over 6.5 minutes) to traverse the distance from parking lot to platform and vice versa. From the collected data, it appears that Japan offers more bus service than any other type of public transportation, followed by railway (which includes local rail, light rail, subway and metro). However, the type of public transportation offered to passengers may depend on the type of city and its infrastructure. For example, railway would be used most in highly populated areas such as Tokyo, which has a very intricate network of local rail and subway service, while residents of a smaller rural area would choose bus, taxi or car. Regarding to the number of facilities offered at HSR stations, bus stops and taxi outpace other modes, with an average of 13 and eight facilities per station, respectively. Railway facilities average seven per station, with car and bicycle parking lots coming in last at respective averages of seven and three facilities per station.

Table 18 Descriptive Statistics

(Averages)	Bus	Taxi	Railway	Car	Bicycle
Transfer Time (sec)	349.35	317.3	370.9	397.45	354.85
Number of Services	9.41	-	3.03	-	-
Number of Facilities	13.11	8.19	6.68	5.59	2.73

The descriptive statistic variables for high-speed rail stations with total ridership were plotted against the ridership numbers for each of its stations. Figures 26, 27 and 28 show the plotted results. From Figure 26, it can be seen that there may be a positive relationship between the number of services and ridership. Figure 27 shows that ridership for a transportation mode tends to increase with the number of facilities offered, relative to ridership for all modes collectively. Figure 28 demonstrates that the same relationship can be seen regarding ridership and transfer time.

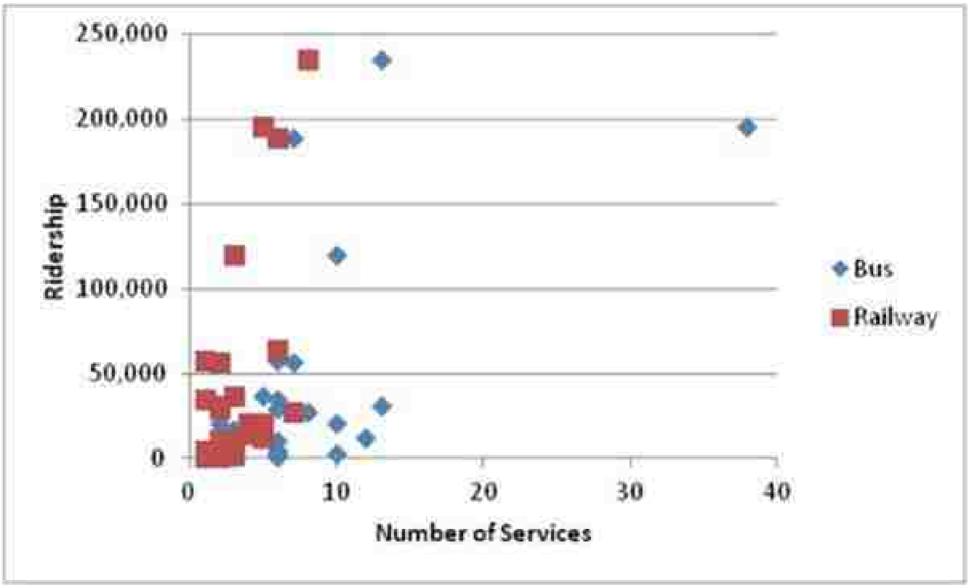


Figure 26 Ridership vs. Number of Service

The data were analyzed using a linear regression model to identify relationships between the descriptive and ridership data. The analysis was performed with the statistical software package in Microsoft Excel. The results listed in Table 19 (correlation coefficients are in Table 20) indicate that the number of bus services, taxi stands and railroad stops significantly impact ridership. That is the greater the number of services and facilities, the higher the ridership.

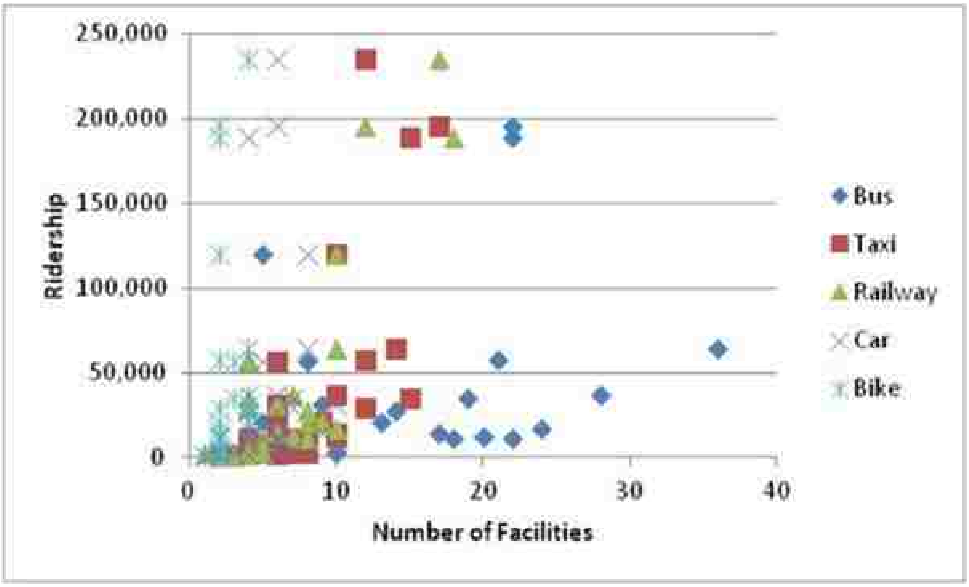


Figure 27 Ridership vs. Number of Facilities

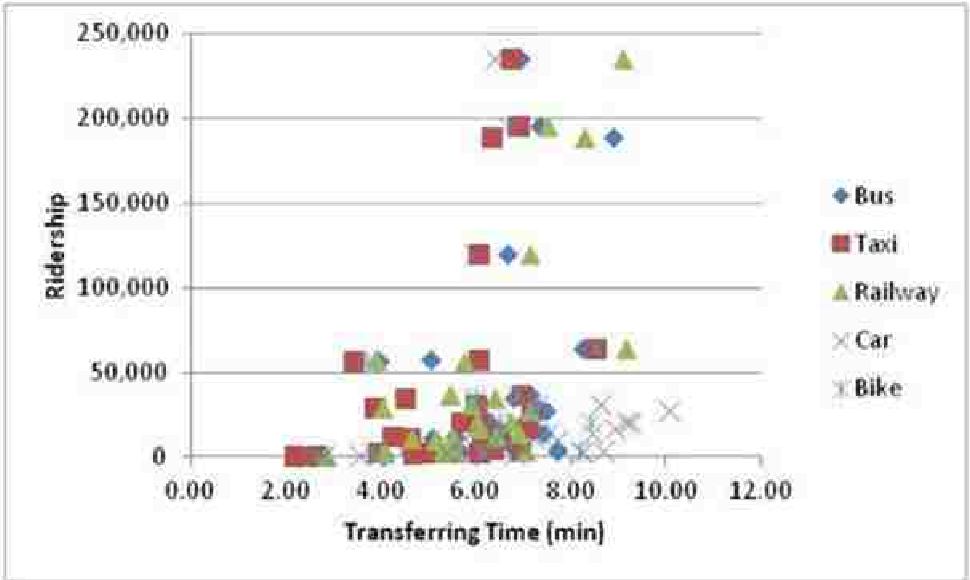


Figure 28 Ridership vs. Transfer Time

Table 19 Regression Results

	Coefficients	Standard Error	t Stat	P-value
Intercept	-49169.54	25340.97	-1.94	0.07
Taxi Transfer Time	12.53	96.49	0.13	0.90
No. of Bus Services	2313.00	1007.08	2.30	0.03
No. of Bus Stops	-1858.90	996.90	-1.86	0.08
No. of Taxi Stands	5770.79	2448.14	2.36	0.03
No. of Railway Stations	9981.38	1893.06	5.27	0.00
No. of Car Parks	-2993.69	3603.65	-0.83	0.42
No. of Bike Parks	-741.85	7002.49	-0.11	0.92
R-Square	0.841817112			
Adjusted R-Square	0.786453102			
Observations	28			

Table 20 Correlation Coefficients

	Ridership	Taxi Transfer Time	No. of Bus Services	No. of Bus Stops	No. of Taxi Stands	No. of Railway Stations	No. of Car Parks	No. of Bike Parks
Ridership	1							
Taxi Transfer Time	0.34	1						
No. of Bus Services	0.59	0.16	1					
No. of Bus Stops	0.27	0.6	0.13	1				
No. of Taxi Stands	0.66	0.4	0.48	0.59	1			
No. of Railway Stations	0.82	0.51	0.34	0.45	0.57	1		
No. of Car Parks	0.1	0.41	0.14	0.2	0.39	0.1	1	
No. of Bike Parks	0.19	0.44	0.1	0.28	0.22	0.29	0.33	1

Data Analysis - China

The characteristics of high-speed rail stations in China are listed in Table 22. There are just a few stations included in the data that have BRT and subway connection, and there are no bicycle facilities found on these stations, thus the descriptive data for other modes are more revealing. It can be seen from the table that there are more bus stops/terminals at these high-speed rail stations than the facilities for suburban bus, cars and taxis. The transfer time for the passengers from buses is longer than for those arriving by suburban bus, car and taxi.

Table 21 Descriptive Data

	BRT	Subway	Bus	Suburban bus	Bike	Car	Taxi
Number of Service	1.50	1.00	14.19	5.33			
Number of Facilities	1.50	1.00	4.36	1.33	0.00	1.11	1.11
Interval	5.25	8.25	8.78	40.00			
Transfer Time	8.34	3.78	5.79	5.26	N/A	3.38	1.84

The relationship between ridership and the four categories of factors (number of services, service intervals, number of facilities and transfer times) are presented in Figures 29, 30, 31 and 32. Figure 29 shows that the number of bus service lines is greater than those offered by subway, BRT and suburban buses. Bus, BRT and suburban bus services may be associated with high ridership. It can be seen from Figure 30 that stations having BRT and subways have short service intervals similar to suburban bus service. The associated ridership varied significantly.

Figure 31 indicates that there are substantially more bus stops, car parking facilities and taxi stands than there are BRT stops, subway stations and suburban bus stops. However, there may be no association between high ridership and the presence of many bus stops. It can be observed from Figure 32 that cars, taxis, subways and suburban buses tend to have shorter transfer times. However, these shorter times may not be associated with high ridership.

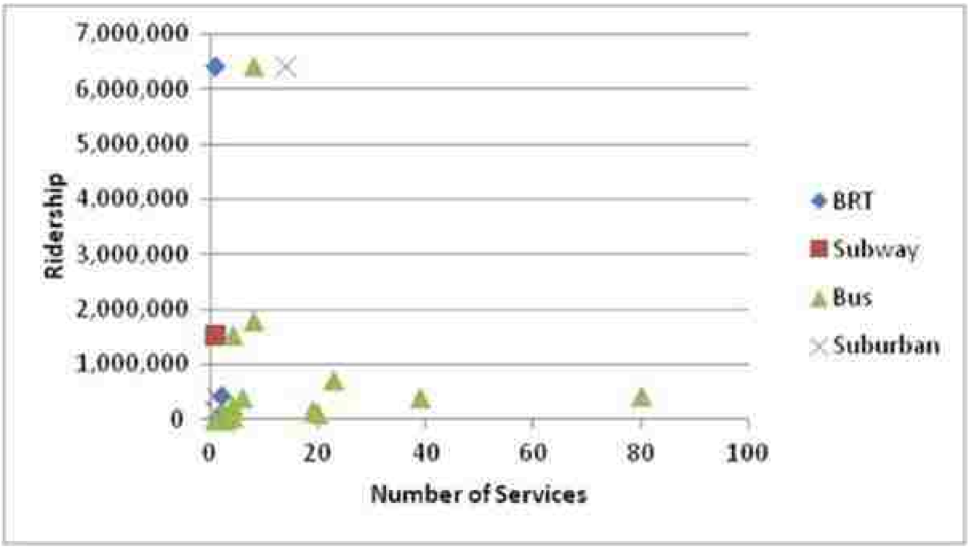


Figure 29 Ridership vs. Number of Services

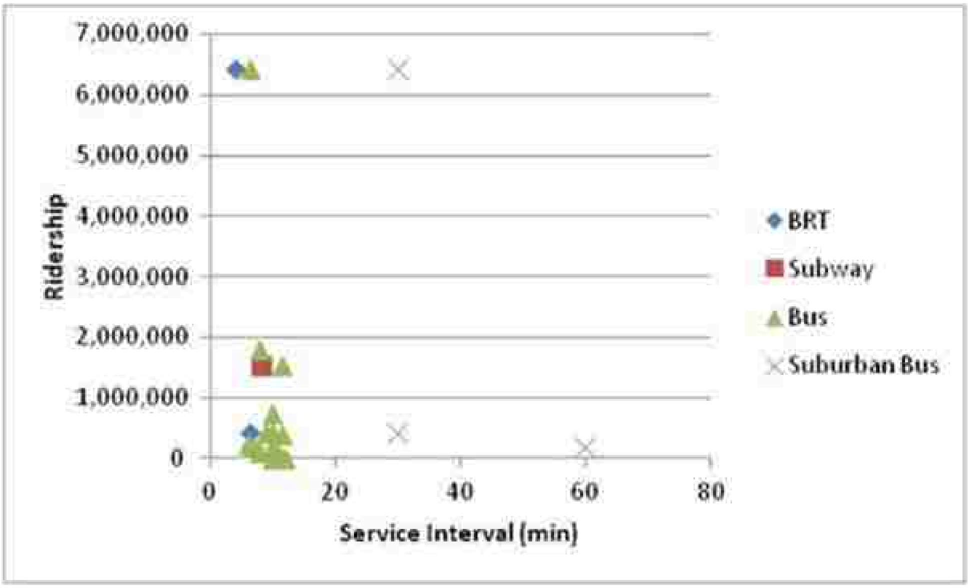


Figure 30 Ridership vs. Service Interval

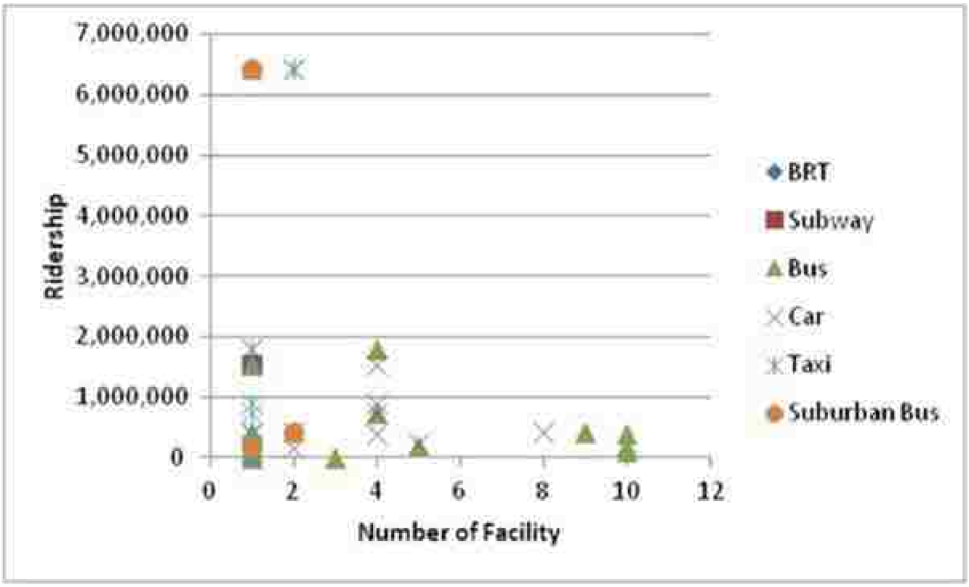


Figure 31 Ridership vs. Number of Facilities

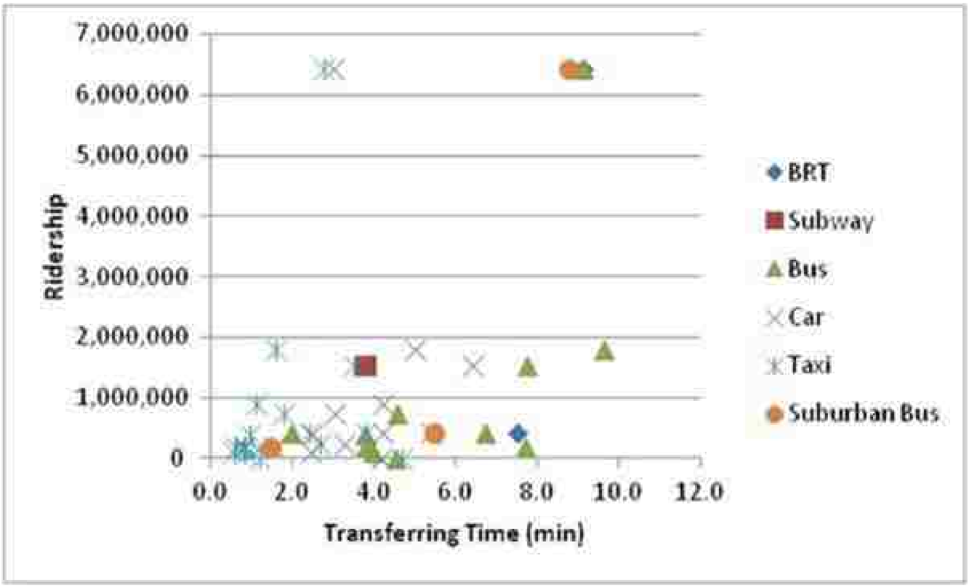


Figure 32 Ridership vs. Transfer Time

Regression analysis was performed for ridership in relation to the four categories of influencing factors. The original data were standardized before the regression was conducted.

The standardized regression results are presented in Table 22. There are large VIF values in the result which indicates that there is high multi-collinearity among predictors. In order to reduce the high VIF values, a new predictor was defined. TIME is defined as a sum of the "time" predictors as shown in equation (6):

TIME = BusInterval + BusTransferTime+CarTransferTime+1.4*TaxiTransferTime (6)

The adjusted regression results are listed in Table 23. Since "BusLines" and BusStops" have high VIF values, two separate regressions were conducted by dropping one of these two predictors. The results are shown in Table 24 and Table 25. Since the results in Table 25 has a higher R-square value which is 89.4% than the one with "BusStops" as a predictor, so the result of Table 25 was used.

Table 22 Standardized Regression Results

	Coefficient	**Standard Error**	**t-Statistics**	**P-Value**	**VIF**
Constant	811769	159261	5.1	0.649	
BusHeadway	-750495	342810	-2.19	0.06	4.361
BusLines	-1390949	580718	-2.4	0.043	12.514
BusStops	-657671	591136	-1.11	0.298	12.967
CarParking	275741	372277	0.74	0.48	5.143
TaxiStands	1589465	249421	6.37	0	2.308
BusTransferTime	-604238	326930	-1.85	0.102	3.966
CarTransferTime	-648899	302726	-2.14	0.064	3.401
TaxiTransferTime	-1029799	381393	-2.7	0.027	5.398
R-Square	90.90%				
R- Square(adj)	81.80%				

Table 23 Adjusted Regression Result

	Coefficient	Standard Error	t-Statistics	P-Value	VIF
Constant	811769	138803	5.85	0	
BusLines	-1403176	496578	-2.83	0.016	12.046
BusStops	-540832	481477	-1.12	0.285	11.325
CarParking	236299	280810	0.84	0.418	3.852
TaxiStands	1582589	216087	7.32	0	2.281
Time	-623785	157838	-3.95	0.002	4.198
R-Square	90.50%				
R- Square(adj)	86.20%				

Table 24 Regression Result-1

	Coefficient	Standard Error	t-Statistics	P-Value	VIF
Constant	811769	174586	4.65	0.001	
BusStops	-1677430	332841	-5.04	0	3.421
CarParking	-412581	203287	-2.03	0.065	1.276
TaxiStands	1178077	203593	5.79	0	1.28
Time	-815762	179195	-4.55	0.001	3.42
R-Square	83.60%				
R- Square(adj	78.10%				

Table 25 Regression Result -2

	Coefficient	Standard Error	t-Statistics	P-Value	VIF
Constant	811769	140309	5.79	0	
BusLines	-1869171	275883	-6.78	0	3.639
CarParking	445201	212681	2.09	0.058	2.163
TaxiStands	1717832	181384	9.47	0	1.573
Time	-486495	100955	-4.82	0	1.681
R-Square	89.40%				
R- Square(adj	85.90%				

Comparison of High-Speed Rail Stations

Multimodal connectivity at high-speed rail stations in various countries presents a variety of profiles. Figure 33 shows the number of public transportation services connected to high-speed rail stations. Other public transportation modes including BRT and tramway are connected to HSR stations in these countries. Because their sample sizes included in this study are small, these modes are not presented in Figure 33. From Figure 33 it can be seen that the high-speed rail stations in China offer connections to more bus lines than do those in other countries. Subway connections in these other countries also are at the same level. Note that the sample size in this study (i.e., number of stations with subway connections) is small, particularly for China and Spain. France and Japan have at least two subway lines connected to their HSR stations.

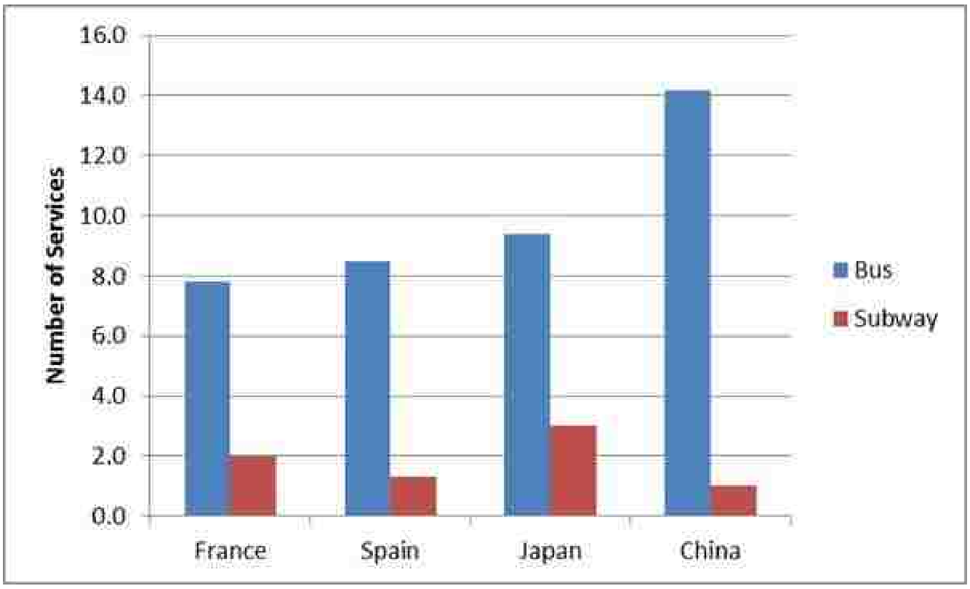


Figure 33 Number of Services in Other Countries

Regarding to connection facilities, Figure 34 shows that the number of facilities for buses within the HSR system in China is not high, although each serves more bus lines than in other countries. This is due to the fact that these lines share bus stops/terminals at HSR stations, which is the same for Spain. Relatively, there are more bus stops/terminals provided in France. Stations in France and Japan offer many subway stops. Sometimes there is more than one subway stop per station per line. France has more car parking than the other countries in this study, followed by Japan and Spain. The HSR stations in China offer the smallest number of car parking facilities. Japan has more taxi stands at their HSR stations than other countries in the study. In France, there are significantly more parking facilities for bicycles than in other countries in the study. China, a country known for its bicycle use, does not have any bicycle parking at the 17 HSR stations covered in this study. This may be due to the fact that the stations are located outside of cities, making bicycle access impractical.

Transfer times also present different profiles. From Figure 35, it can be seen that the transfer times in Japan and China, regardless of connection mode, are significantly higher than those in France and Spain. Among the various modes, transfer time is longest by bus, while other modes offer transfer times relatively comparable to those in France and Spain. Spain boasts the shortest transfer times of any country in all modes, particularly for taxis. This might be related to the fact that taxi service is so inexpensive in Spain that it is used even for daily errands, such as shopping.

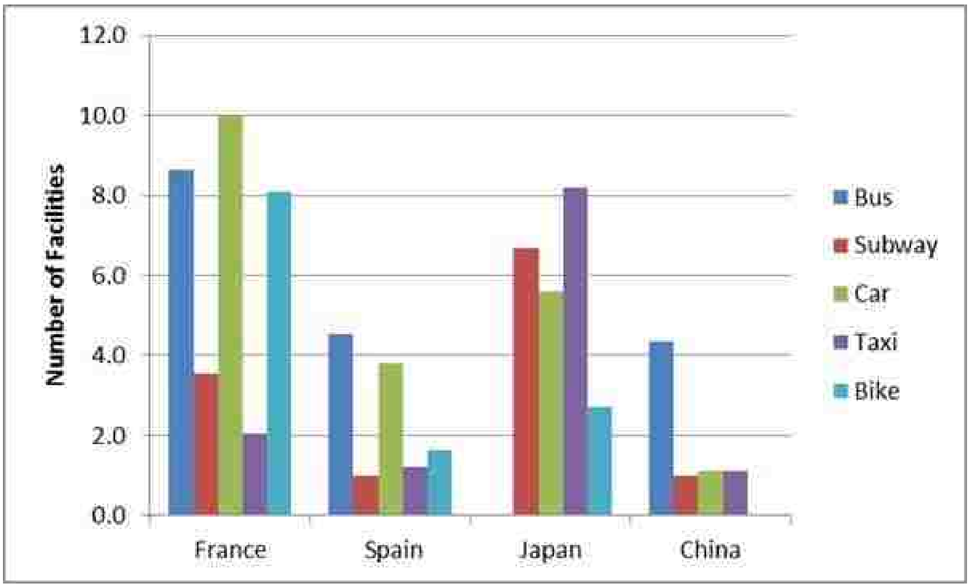


Figure 34 Number of Transportation Facilities in Other Countries

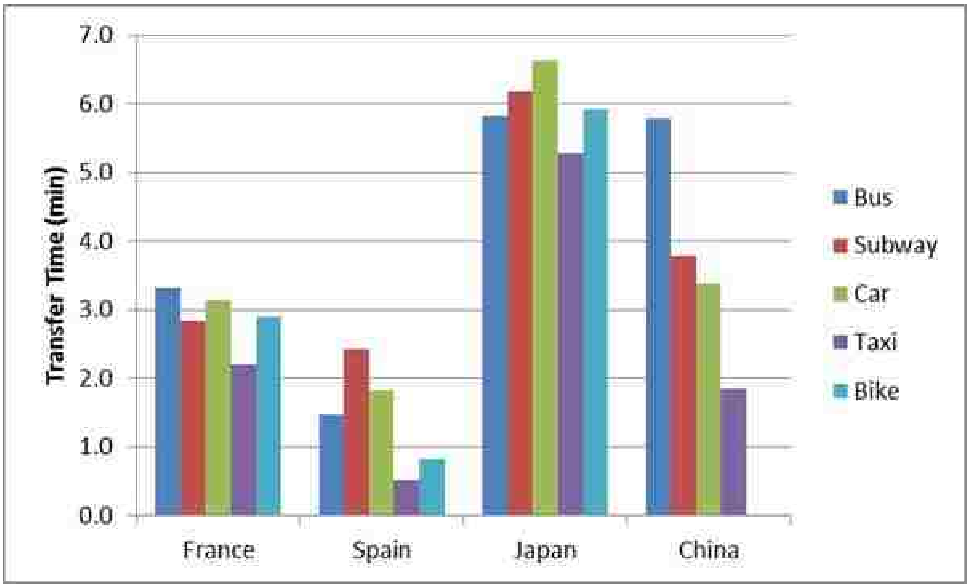


Figure 35 Transfer Time in Different Countries

From an operations perspective (see Figure 36), France has the longest average bus arrival interval in the study—more than twice that of China. Arrival intervals in Japan were not studied because the data could not be easily extracted. Subway train arrival intervals in France are shorter than those in Spain and China. Spain has the longest train arrival intervals in the study—up to ten times longer than France.

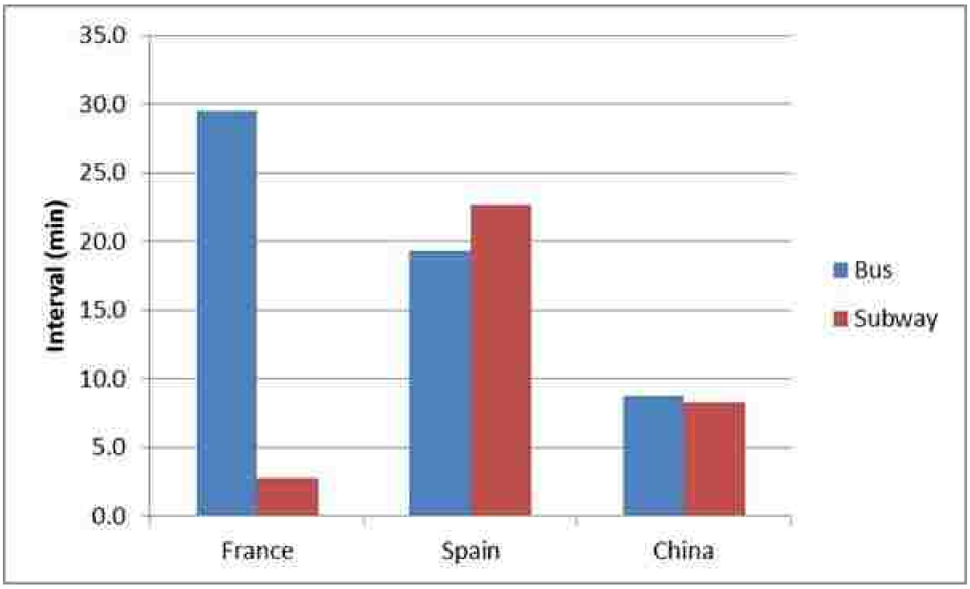


Figure 36 Service Intervals in Different Countries

VI. Conclusions and Future Study

Connectivity as an Influence on High-speed Rail Ridership

The results from the regression analysis for the four countries are listed in Table 26. It can be seen that all four categories of connectivity variables influence ridership in these countries in different ways. Bus, subway and regional railroad service influences ridership significantly.

The number of bus services influences ridership in three of the countries, France being the exception. The more bus services connected to high-speed rail stations, the higher the ridership at these stations. Subway, light rail and traditional rail are high-capacity modes of transportation. Their connection to high-speed rail stations always implies high ridership. The sample sizes for HSR stations with these high-capacity connecting modes were small; thus, the impact of the number of services of these modes cannot be derived from the regression analysis. However, the charts illustrate a high-impact relationship between ridership and these connecting modes.

The number of facilities provided for bus, subway, bicycles and taxis also appears to have a significant impact on ridership. The more bus and subway stops, bicycle parking, and taxi stands, the higher the HSR ridership. Note that parking facilities for private cars are not identified as an influencing factor. No such facility factor was identified for HSR ridership in France.

Table 26 shows that the only factor significantly influencing ridership in France is regional rail train arrival intervals. Operation of this mode did not influence HSR ridership in Spain and Japan (data were not available for Japan).

Transfer time is identified to be a significant influencing factor: RER and bicycle transfer time in France, and taxi transfer time for China.

Influencing factors vary by country. In France, ridership appears to be most influenced by RER services, arrival intervals, and transfer times, and by bicycle transfer time.

Passengers who use these two modes have unique characteristics and may constitute a significant population. In Spain, the influencing factors are bus service and facilities, as well as facilities for bicycle parking and taxis. Transfer time and arrival intervals are not shown to be significant. It appears that the availability of a connection mode is more important than its transfer time and arrival intervals. The situation is similar in Japan. In China, bus and taxi service are important to ridership. Transfer times for taxi passengers are significantly shorter than for other modes, and this is associated with higher HSR ridership.

Table 26 Connectivity Influencing Factors

	Number of Service	Number of facility	Interval	Transfer time
France	Number of RER services		RER interval	RER and bike transfer time
Spain	Number of bus services	Number of bicycle parking stations, bus stops, taxi stands		
Japan	Numbers of bus and railway services	Taxi stands and railroad stops	N/A	
China	Number of bus lines	Number of taxi stands		Taxi transfer time

Implications for California High-speed Rail

The findings from this study have significant implications for high-speed rail in the U.S. Figure 37 presents multimodal public transportation connectivity for each station in the proposed California high-speed rail system. Accommodations for private modes, such as car, taxi, bicycle and pedestrians are not indicated but may be assumed. The following insights are offered:

First, special attention should be given to bicycle and pedestrian accommodations. Transit-oriented development will occur around high-speed rail stations. These developments may produce passengers within walking or cycling distance of the station. This is also true for stations that will be developed from existing transit facilities in the San Francisco and Los Angeles metropolitan areas where bicycle facilities may have already been established. Additional bicycle facilities should be provided when high-speed rail is added. From the experiences of other countries, such as France, it can be concluded that high-speed rail stations with bicycle facilities see higher ridership than those without.

Second, transforming an existing transit station into a high-speed rail station will cause some connections to have excessively long transfer times because they were not originally designed for high-speed rail. In China, for example, some high-speed rail stations are older stations that were adapted for HSR. Thus, when weighing the tradeoff between building a new station and adapting an existing one, transfer time for all connections should be taken into account.

Third, a more convenient fare payment system should be used to facilitate transfer between high-speed rail and other modes of transportation. Since the fare structure for high-speed rail differs from that of other modes, additional fare collection systems may be needed to reduce ticketing time, one of the components of transfer time. New technologies that eliminate fare collection at stations altogether may be considered for this purpose.

Fourth, coordinating the arrivals and departures of different modes of transportation at high-speed rail stations is very important. In general, passengers disembarking from high-speed rail trains may have to wait an exorbitant length of time for the arrival of local transit, which would not only increase transfer time but also crowd waiting areas.

Implications for Nevada High-speed Rail

XpressWest is a proposed high-speed rail between Las Vegas and Los Angeles. Several locations have been proposed for the Las Vegas station, one of which is presented in Figure 38. This location, at the intersection between Flamingo Rd. and U.S. Interstate 15, is in close proximity to the Las Vegas Strip. For this project, it is expected that most passengers will be tourists whose visits primarily occur on weekends. Train arrivals and departures would therefore peak from Friday to Monday. Cars, taxis and shuttle buses are currently the primary modes of transportation, and it is expected that this will continue to be the case after the HSR is built.

Based on the experience of other countries, recommendations for Nevada HSR are as follows:

First, pedestrians and bicycles may be the major transit mode at the start of operation. This is because there are three residential towers to the south that are within walking distance of the proposed station. The station must provide access and accommodations for these potential passengers. It is expected that transit-oriented development around this station will generate demand for a commute between Los Angeles and Las Vegas. In that case, additional pedestrian and bicycle facilities should be provided.

Second, the peak use anticipated on weekends makes it necessary to establish a light rail or similar local transportation mode that can accommodate large numbers of passengers arriving simultaneously. A continuously operating light rail service running the length of the Strip would be ideal for this purpose. Scheduled to accommodate peak arrival periods, the light rail would quickly transport passengers from the train to destination casinos and hotels.

Figure 37 Full High-Speed Rail System with Connections

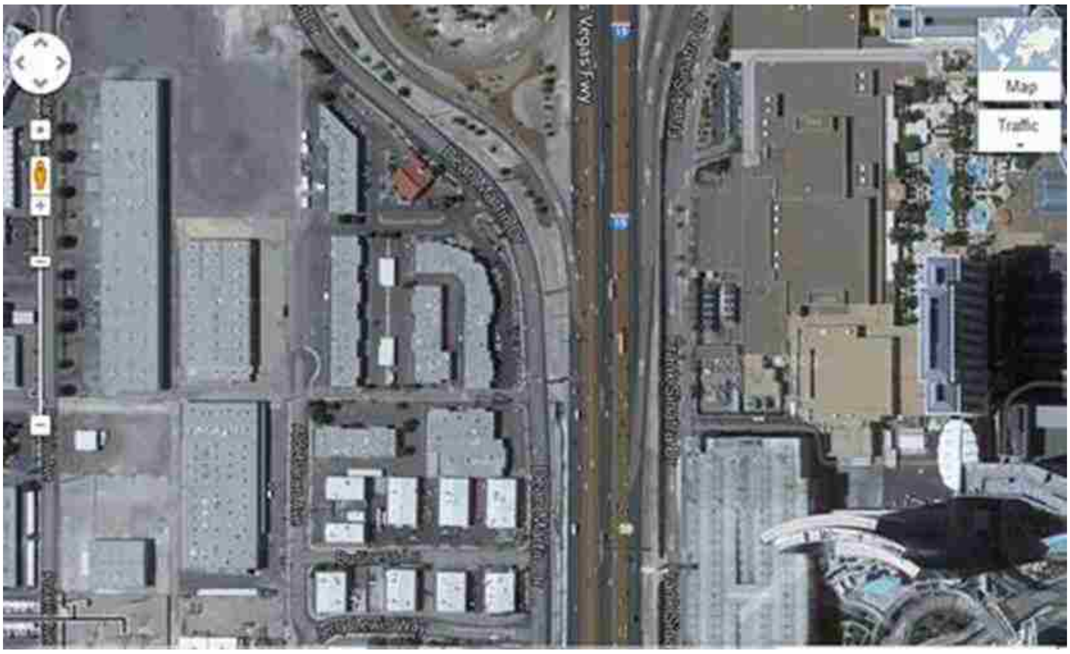


Figure 38 Optional Station for XpressWest in Las Vegas

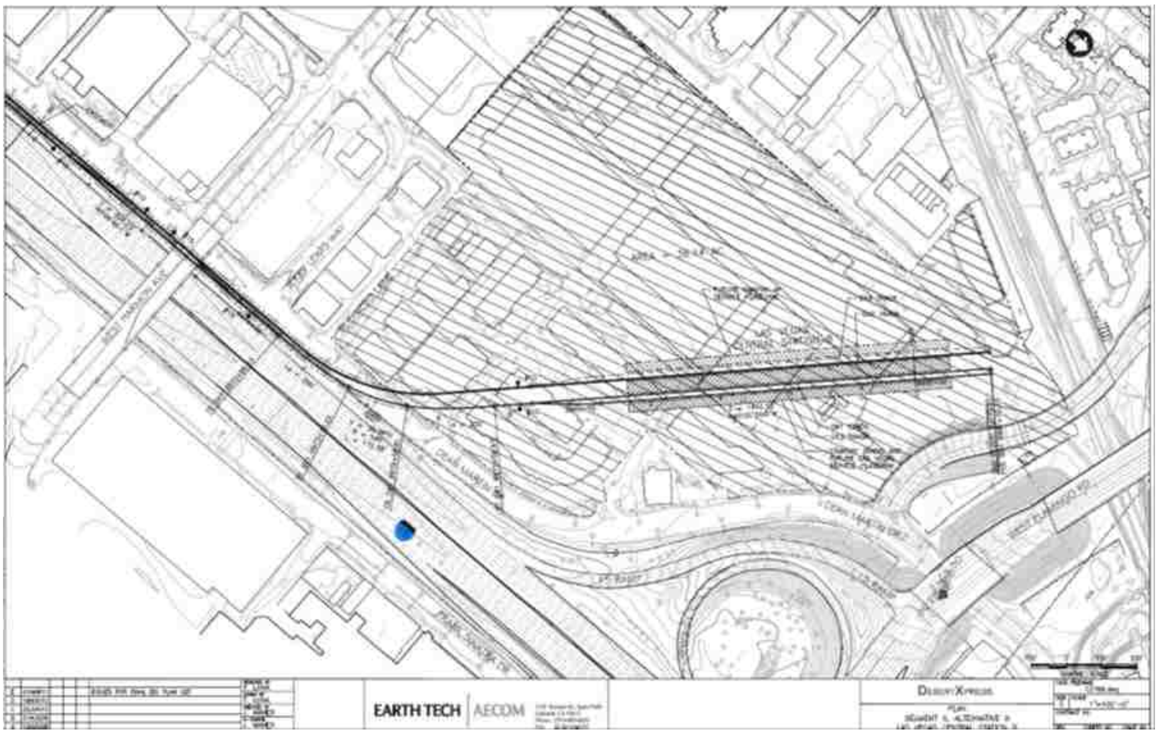


Figure 39 One Proposed XpressWest Station in Las Vegas

Future Study Needs

The following improvements would yield observations that are more conclusive:

1. The sample size for high-speed rail stations with railroad connections is small. Only two such stations in Spain and one in China were included in the data analysis of this study due to a lack of ridership data for the others. There are in fact many stations in China with railroad connections.

2. The railroad data for Japan encompass all the various modes of rail transportation, including light rail, traditional rail and subways. Given this mix of modes, the ability to analyze the data is limited.

3. No operational data were collected for Japan, further limiting analysis. This study can be improved if such data can be made available.

4. The analysis conducted in this study can be improved by distinguishing urban stations from those in rural areas. HSR stations in cities exhibit different layout characteristics than those in rural areas.

5. Layouts of high-speed rail stations should be obtained. From these layouts, different measures of layout should then be obtained for analysis. In this study, there is just one variable—transfer time—used for analysis. With more variables representing the layout, the impact of connectivity can be evaluated more thoroughly.

6. The data from these four countries can be combined for analysis. Then the unique characteristics that influence ridership can be identified in a more convenient and comprehensive manner.

Appendix A

Table 27 Correlation Coefficients

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
bikefac	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
carfac	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
taxifac	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
number	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix B

Table 28 Abbreviations and Acronyms

AVANT	Medium-distance high-speed rail system in Spain
AVE	Alta Velocidad Española
BRT	Bus Rapid Transit
HSR	High-Speed Rail
INSEE	Institut National de la Statistique et des Études Économiques (France)
LGV	Ligne a Grande Vitesse (France)
PDL	Passenger-Designated Lines
RFF	French Rail Network
SNCF	French National Railway Corporation
TGV	Train à Grande Vitesse

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