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High-Speed Rail Station Interconnectivity and Ridership

Hualiang (Harry) Teng[1], Tarik Toughrai[2], Tingting Yu[1], Russell Ozawa[1]

[1]Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, Nevada
[2]School of Engineering, The Ecole Nationale des Travaux Publics de l'Etat, Lyon, France
Email: hualiang.teng@unlv.edu

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Abstract

The objective of this study was to quantify multimodal connectivity of HSR stations and its impact on ridership in four countries: France, Spain, Japan and China. In this study, multimodal connectivity is measured by the number of different modes of transportation connected to HSR stations, the number of installed arrival and departure facilities for each mode, the transfer time from connecting modes to boarding platforms at HSR stations, and the arrival time intervals of public transportation modes. Data were collected from HSR systems of these four countries. The relationship between ridership and the characteristics of multimodal connectivity was identified using regression models developed in this study. All the connectivity variables considered in this study influence ridership in these four countries in different ways. On the whole, bus, subway, and regional railroad services influence ridership significantly. For instance, the more bus services connected to the station, the higher the ridership. This trend is apparent in three of the four countries, France being the exception. Also, subway, light rail, and traditional rail are modes of high-capacity transportation. Their connection to HSR stations always implies high ridership for high-speed rail. The number of facilities also shows significant impacts on HSR ridership. For instance, the more bus and subway stops, and the more bicycle parking and taxi stands, the higher the ridership. Transfer time also has a significant influence.

Keywords

High Speed Rail, Multimodal, Connectivity, Ridership, Regression Analysis

1. Introduction

Research on high-speed rail in the U.S. has typically been conducted from an economic perspective. Sands' report [1] 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 [2] and Murakami and Cervero [3] focused their studies on the economic impact around high-speed rail stations, while Loukaitou-Sideris *et al*. [4] 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 [5] focus on providing adequate public transit connection to high-speed rail stations proposed for Orlando, Florida. That study discusses many existing bus routes that represent HSR connection opportunities. A study by City of Fresno [6] 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 location in the city and the land use 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 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 route) provided by each connecting mode, the number of facilities (e.g., bus stop and subway station) for different modes, transfer time from different modes to high-speed rail stations, and scheduled service arrival intervals were collected from different 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 relationship between ridership and the characteristics of multimodal connectivity of high-speed rail stations was then identified through regression models. Implications of the finding on the high-speed rail in California and Nevada are discussed in this study.

This paper includes five sections. The first section presents the background and problem statement. The second section discusses the methodology used. Section 3 provides a brief literature review. Data collection and analysis are covered in Section 4. Section 5 presents conclusions, implications of findings, and areas for further study.

2. Methodology

Factors that influence the ridership of high-speed rail were identified in this study through the process starting with a literature review. 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. 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 spaces
  - Number of bicycle parking lots
- Transfer time
- Service interval in peak periods
- Ridership for high-speed rail stations

The data sources differed for each country.

Transfer time for each mode is defined as the time required to traverse the distance between the drop-off point 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 m/s. Delays encountered at obstacles such as stoplights are not taken into account in the calculation. An additional 30 seconds is added if the traveler needs to 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.

The ridership data was 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:

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

where, $\beta_0, \cdots, \beta_p$ 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.

3. Literature Review

3.1. Multimodal Connectivity

Mbatta [7] conducted a study on developing and evaluating the criteria for transit stations with a focus on multimodal connectivity. The study presents 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 seat in a transit vehicle. It 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 have to 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.* [8] discussed: 1) what criteria passengers use to evaluate transit stops and stations, and 2) what factors influence their evaluation 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 Metropolitan Transportation Commission (MTC) Transit Connectivity study conducted in 2006 [9] indicated that, for transit hubs, the keys to success include reliable service, three-minute maximum transfer time, effective wayfinding, 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 Transit-Oriented-Development (TOD) 202: Station Area Planning—Reconnecting America [10], 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), and 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.

3.2. Transit Ridership

Taylor and Fink [11] provided a literature review of the studies on transit ridership. The ridership studies were classified into descriptive and causal approaches. 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, where 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. Wu [12] also identified some factors that can influence the ridership on high speed rail in China.

There is a different category of ridership model that focuses on transit stations. One example is the study by Chan and Miranda-Moreno [13] where 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.* [14] 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 BRT stops.

3.3. High-Speed Rail Connectivity and Ridership

Only a few studies address multimodal connectivity at high-speed rail stations. Gregg and Begley's [5] 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 [6] 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 [1] is one of 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 with regard to high-speed rail development in California. Nuworsoo and Deakin [2] and Murakami and Cervero [3] focused their studies on the economic impact on areas surrounding high-speed rail stations, while Loukaitou-Sideris *et al.* [4] looked into the impact of high-speed rails 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.

4. Data Collection and Analysis

4.1. The Case 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 built along old railway lines.

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.

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. Most stations on an LGV line outside of Paris are new construction with simple and modern design. They are typically located on the city's periphery. The data for this study were collected for the 34 French high-speed rail stations.

The data collected in this study were analyzed using a linear regression model. It was found that these four sets of variables are highly correlated: transfer time, schedule, number of service, and number of facilities, which suggests that not all the variables can be included in the regression modeling. **Table 1** 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.

4.2. The Case in Spain

Spain's high-speed rail system is the Alta Velocidad Española (AVE). Spanning 1900 miles (3100 km), it 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). In this study, the data was collected for sixteen high-speed rail stations in Spain.

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 2**. The data that have small sample size were removed from the regression analysis. The correlation coefficients of the variables included in the regression models are calculated. From **Table 2** 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 1. Linear regression results for France.

Independent Variable	Estimated Coefficient	Standard Error	t-Statistic
Constant	1.35907e+002	51.04971	2.66225
RER Transfer Time	−0.13361	2.54636e−002	−5.24718
Subay Transfer Time	9.84538e−003	1.43825e−002	0.68454
Tramway Transfer Time	−2.64553e−003	1.46650e−002	−0.18040
Bus Transfer Time	8.47004e−002	0.16407	0.51623
Bike Transfer Time	−0.15232	3.80119e−002	−4.00710
Car Transfer Time	−0.14540	0.15921	−0.91331
Taxi Transfer Time	8.04043e−002	0.20022	0.40158
Bus Interval	−8.06694e−002	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	−0.16560
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+003		
Standard Error of the Regression	20.28935		
Durbin-Watson Statistic	1.61997		
Mean of Dependent Variable	16.37324		

Table 2. Regression results for Spain.

	Coefficients	Standard Error	t Stat	p-value
Intercept	−4.9913	1.6237	−3.0740	0.0180
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	0.0000	0.0000	0.6799	0.5184
Bus Transfer Time	0.0000	0.0000	−0.8538	0.4214
Taxi Transfer Time	1.1405	0.9397	1.2137	0.2642
Bike Transfer Time	0.0000	0.0000	1.2300	0.2584
Car Transfer Time	0.9069	0.4618	1.9635	0.0903
R Square	0.941526886			
Adjusted R Square	0.874700469			
Observations	16			

4.3. The Case 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 in the works. The Shinkansen basically runs the entire length of Japan, which mostly form a contiguous line. The Shinkansen is currently broken up into six main lines, as well as two mini-Shinkansen lines (which is the concept of upgrading narrow gauge railway lines to standard railway lines for Shinkansen use).

The data collection for this study includes 37 high-speed rail stations in Japan. To ensure diversity the stations were selected randomly from among those that had maintained ridership records. The data collected in this study were analyzed using a linear regression model. The results listed in **Table 3** indicate that the number of bus services, taxi stands, and railroad stops significantly impact ridership. The greater the number of services and facilities, the higher the ridership.

4.4. The Case 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 5800 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

Table 3. Regression results for Japan.

	Coefficients	Standard Error	t Stat	p-value
Intercept	−49,169.54	25,340.97	−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		

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.

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 east and west. Together, these corridors cover 12,000 km. 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 to be completed by 2020. Due to influx of economic plan stimulus funds, many lines now project considerably earlier completion dates.

According to the "Mid-to-Long-Term Railway Network Plan" revised in 2008, 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, though 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. Some data for other major high-speed rail stations, such as Beijing South, were also collected. Because ridership data cannot be made available to these stations, they were not included in this study.

Regression analysis was performed for ridership in relation to the four categories of influencing factors. The regression results are presented in **Table 4**. Variables related to BRT, subway, bicycle, and suburban bus are excluded from the analysis because the sample for these modes is small. It can be observed from **Table 4** that three variables are significant at the level of 0.95: number of bus lines, number of taxi stands, and taxi transfer time. The coefficient of the number of bus line is negative, which implies that the ridership may not be high when there are many bus lines connected to a high-speed rail station. The coefficient for the number of taxi stand is positive, indicating that higher ridership should result from providing more taxi stands at high-speed rail stations. This may portray the situation of the high-speed rail stations for which the data were collected in this study. Data for some major high speed rail stations in China

Table 4. Regression results for China.

	Coefficients	Standard Error	t Stat	p-value
Intercept	−789,688	1,671,846	−0.47	0.65
Bus Interval	−47	21	−2.19	0.06
No. of Bus Lines	−68,673	28,670	−2.40	0.04
No. of Bus Stops	−169,726	152,555	−1.11	0.30
No. of Car Park	126,616	170,944	0.74	0.48
No. of Taxi Stands	4,786,021	751,027	6.37	0.00
Bus Transfer Time	−30	16	−1.85	0.10
Car Transfer Time	−41	19	−2.14	0.06
Taxi Transfer Time	−810,580	300,204	−2.70	0.03
R Square		0.909035107		
Adjusted R Square		0.818070213		
Observations		17		

were also collected. These major stations, primarily located in urban areas, were not included in the analysis due to the lack of ridership data. Most of the stations included in this analysis are new and not in urban areas. The variable taxi transfer time is negative, suggesting, reasonably, that high ridership is associated with short transfer time. It should be noted that bus travel may not be convenient for passengers with luggage.

5. Conclusions and Future Study Needs

5.1. Characteristics and High-Speed Rail Stations in Other Countries

Multimodal connectivity at high-speed rail stations in different countries presents different profiles. The high-speed rail stations in China are connected to more bus lines than in other countries. The numbers of bus lines connected to HSR stations in other countries are smaller than that in China. 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.

With regard to connection facilities, 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 other countries, followed by Japan and Spain. The HSR stations in China offer the smallest number of car parking facilities. Japan has more taxi stands located at their HSR stations than other countries. In France, there are significantly more parking facilities for bicycles than in other countries. 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. 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 even used for daily errands, such as shopping.

From an operations perspective, France has longest the average bus arrival interval—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—up to ten times longer than France.

5.2. Connectivity as an Influence on High-Speed Rail Ridership

The results from the regression analysis for the four countries are listed in Table 5. 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 influence ridership significantly.

The number of bus services influences ridership in three 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.

Table 5. 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 service	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

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 5 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.

5.3. Implications for California High-Speed Rail

The findings from this study have significant implications for high-speed rail in the U.S. The following insights are offered below:

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 for exorbitant length of time for the arrival of local transit, which would not only increase transfer time but also crowd waiting areas.

5.4. Implications for Nevada High-Speed Rail

Xpress West is a proposed high-speed rail between Las Vegas and Los Angeles. Several locations have been proposed for the Las Vegas station. 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 usage 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.

5.5. Future Study Needs

The following improvements would yield observations that are more conclusive:

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.

The railroad data for Japan encompass all of 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.

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

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. 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.

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.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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