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DEVELOPMENT OF HIGH-SPEED RAIL IN THE PEOPLE'S REPUBLIC OF CHINA

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Abstract

High-speed rail (HSR) construction is continuing at a rapid pace in the People's Republic of China (PRC) to improve rail's competitiveness in the passenger market and facilitate inter-city accessibility. To take advantage of spillover effects, bring economic cohesion at the local level, and recover the local matching investment in infrastructure, all cities have planned new towns around HSR stations. Speeding up HSR construction has required the development of many standardized technologies and processes. Plans for HSR stations usually situate them in suburbs, far from city centers, to reduce the cost of property right of way relating to the removal of housing or industry as well as to lower the complexities in negotiations. However, city centers remain the main starting and destination terminals for most HSR passengers, especially businessmen who use HSR frequently. Besides, large railway stations in suburbs, providing a comfortable waiting space for passengers, have prolongate the travel time for HSR users. A reliable and high-quality public transit service, connecting an HSR station and the city center at the launch of HSR operations, is essential to curb the increase in car/taxi use. Studies have also suggested that, instead of building one big HSR station in the suburb of a metropolis, constructing multiple stations in the vicinity of city centers will greatly reduce the access/egress time, thereby enhancing the travel efficiency.

Keywords: high-speed rail, multimodal intercity transport, People's Republic of China

JEL Classification: L92, R11, R40, R58

Contents

INTRODUCTION

The People's Republic of China (PRC) is a large country and, with its recent rapid economic growth, there is a huge demand for land transport between regions. Rail transportation plays an important role in this. Since the 1990s, the proportion of rail transit in the inter-city passenger sector has declined because of the development of highways and civil aviation. However, too much reliance on highway transport could cause several environmental, energy, and safety problems. Weather factors like fog and road congestion can reduce the efficiency and reliability of highway transport as well (Maria 2014). Thus, to provide fast and reliable inter-regional transportation, rail service has become important.

This chapter reviews the development of different modes of inter-city transport in the PRC since 1978. The use of rail, measured in rail passenger-km, has grown far less than other modes, especially highways. To provide better rail options, the PRC began experimenting with HSR in the late 1990s. The speed of HSR has increased from its initial 200 km per hour to 350 km per hour.

The PRC government has updated the national railway networks plan with eight "vertical" (north–south) and eight "horizontal" (east–west) passenger corridors, and, on their completion, the national HSR system will be over 30,000 km long in 2020 and 38,000 km long in 2025 (NDRC 2016). Meanwhile, the development of regional HSR will also continue.

Many researchers believe that HSR can bring economic, environmental, and social benefits to the regions and cities that it serves (Feng 2009; Xiao 2011). Researchers have also asserted that areas situated outside the HSR network, but efficiently linked to it, could benefit from the diffuse effects of major urban agglomerations (Javier, Rafael, and Gabriel 1996). US researchers have argued that, in addition, HSR can enable big cities to connect further into the hinterland, where housing and commercial space are more affordable (Sean 2012). However, capturing these benefits also requires attention to station location and design (Yu, João, and Luis 2014).

Chen and Peter found that the PRC's HSR services have substantial and demonstrable effects in aiding the economic transition of cities that are within 2 hours' travel from major urban regions, helping to generate renewed economic growth (Chen and Peter 2011). To accelerate the HSR network construction, the PRC has standardized work processes. To reduce the difficulty of land acquisition, it has mostly located new HSR stations in suburbs, away from large urban centers. This means that access to stations can require a long trip from the city center. The improvement in accessibility that HSR offers has realized the expected development around suburban stations.

In this study, the authors also investigated and analyzed HSR passenger travel behavior and mode choices, using the Shanghai Hongqiao and Shaoxing Station as a case study.

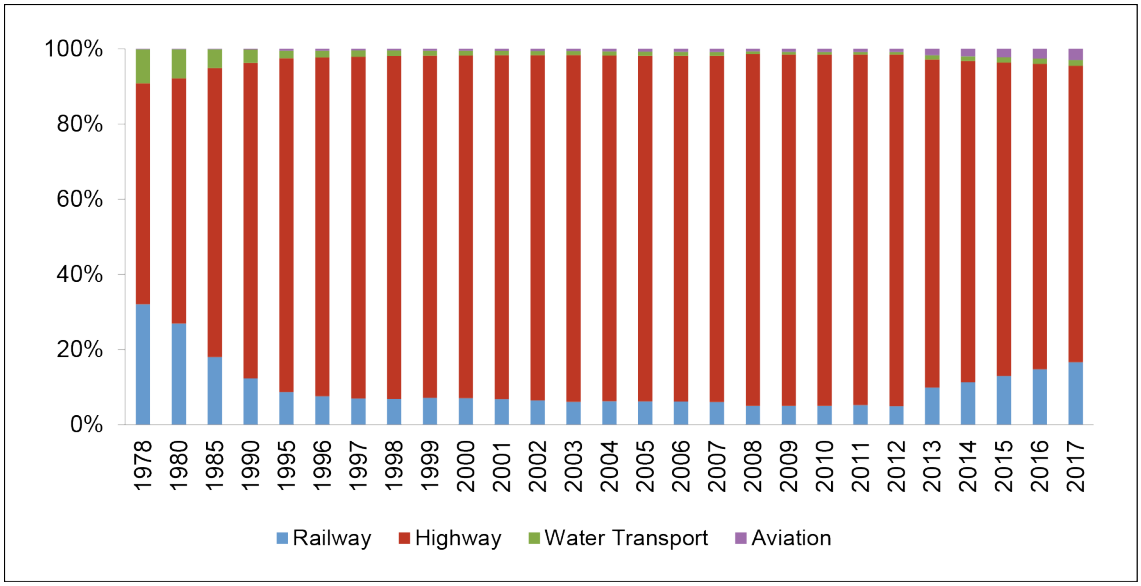
1. MULTI-MODAL INTERCITY TRANSPORT IN THE PRC

The PRC's railway mileage grew from 51,700 km in 1978 to 127,000 km in 2017. The number of rail passengers is also increasing, reaching 3.084 billion trips in 2017. This is a 278.40% increase in passengers over 1978 with an average annual growth rate of 3.47%. Over the last decades, the average annual growth rate of passengers has been even higher, reaching 10% in recent years. Moreover, rail passenger intensity (the number of passengers carried per km) has grown fast since 2007, to 22,694 passengers per km in 2016. It is almost 7 times the highway passenger intensity. The passenger-km

of railway transportation grew from 1,093 billion in 1978 to 12,579 billion in 2016, which is an increase of 1,051%. The passenger-km are growing by 12.52% per year (Fan 2011). As more HSR lines enter service, the expectation is that the passenger-km volume of rail transportation will continue to grow.

However, despite the growth in the rail service and its use, the rail share of inter-city travel had dropped before 2011. The loss of market share reflects the tremendous developments in highway transport (and associated increases in automobile ownership) that have occurred over the last few decades. The PRC's highway mileage grew from 890,200 km in 1978 to 4,770,000 km in 2017. Civil aviation also attracted a substantial share of the inter-city passenger growth in these decades. Consequently, the railway's share in the inter-city passenger market fell dramatically from over 30% in 1978 to around 5% in 2001 and remained constant at around 5% for the following decade (Figure 1).

Figure 1: Proportion of Intercity Passengers Carried by Different Transport Modes

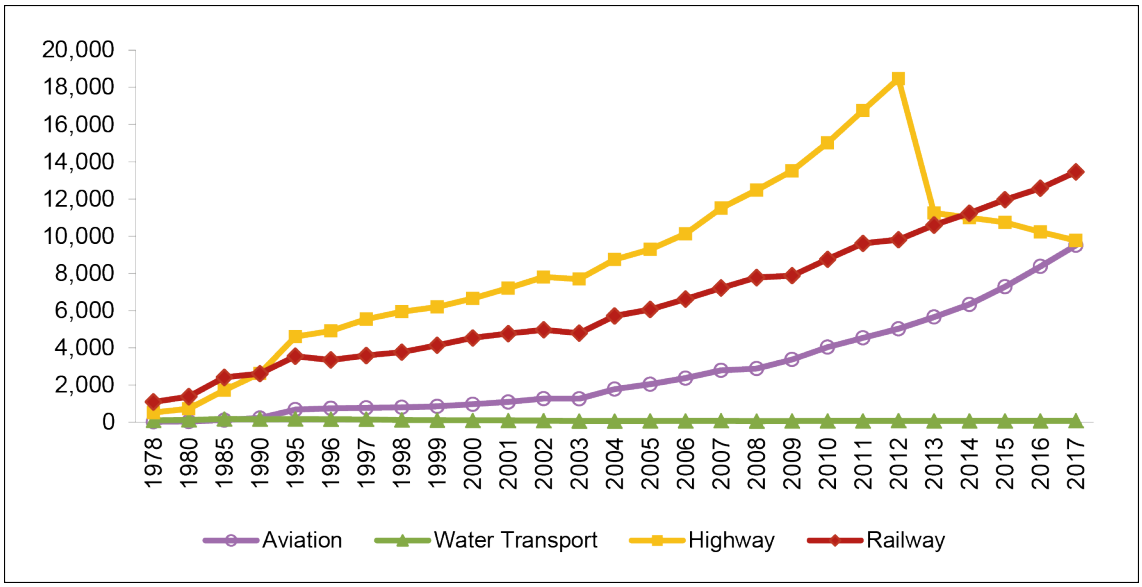


Source: National Bureau of Statistics. 1981–2018.

This changed after 2011. Measured by passenger-km, the rail passenger-km and aviation passenger-km volumes have shown a fairly steady climb in recent years. However, the shrinking of growth in the highway sector is notable (Figure 2). Since 2014, rail has become the dominant sector for inter-city travel in terms of passenger-km.

Today, in the intercity passenger transport market, rail transport has displaced highways as the dominant means of travel. This is true even for travel distances over 300 km, for which rail should be highly competitive. The proportion of civil aviation is also increasing analogously to rail.

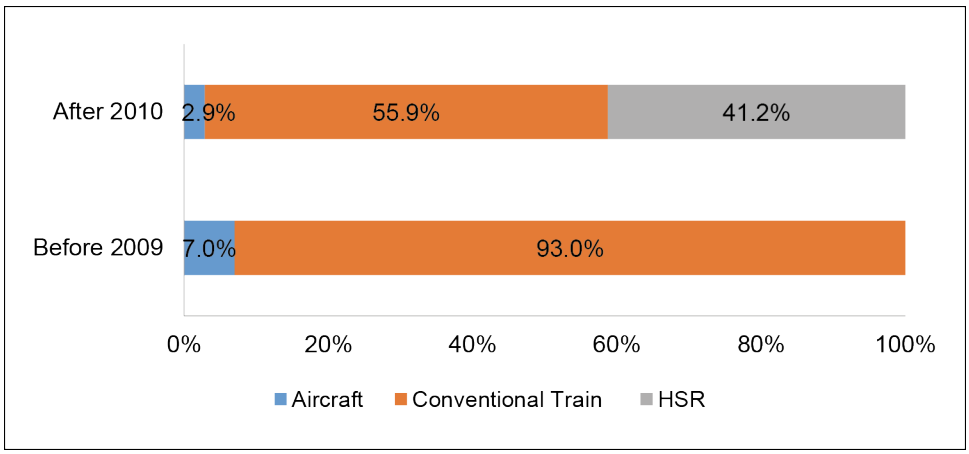
Figure 2: Passenger-km by Different Transport Modes, 1978–2016, the PRC
(100 million passenger-kilometers)



Source: National Bureau of Statistics. 1981–2018.

Thus, many researchers view HSR as a substitute for other inter-city transportation modes, like traditional rail (Givoni 2006; Givoni and Dobruszkes 2013), aircraft (Dobruszkes, Dehon, and Givoni 2014; Bergantino, Capozza, and Capurso 2015), and automobiles (Campos and De Rus 2009). In the PRC, the HSR's launch also changed the mode share for inter-city travel. For instance, the Wuhan–Guangzhou Corridor is an HSR line, connecting two mega cities with a total distance of 1,069 km. A survey that Wu et al. (2014) conducted shows that, before the Wuhan–Guangzhou HSR (started in 2009), conventional rail was the dominant mode of transport along this corridor. Since then, though, HSR has become a significant alternative to traditional rail and aviation (Figure 3). For passengers using HSR, 42% have shifted from road, 52% from conventional rail, and 6% from civil aviation.

Figure 3: Rail and Air Share in the Wuhan–Guangzhou Transport Corridor, the PRC



Source: Wu, Nash, and Wang (2014).

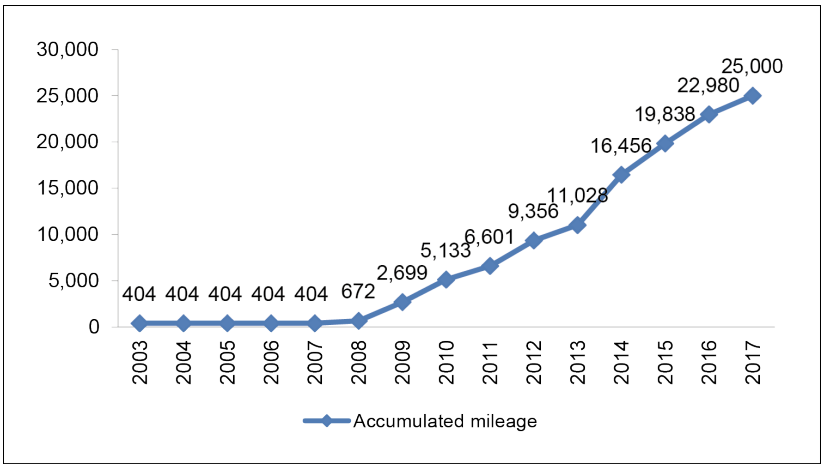
Besides, our analysis and comparisons of data obtained from a survey in Shaoxing allow us to address HSR's role in inter-city leisure travel. The rise of domestic tourism in the PRC has been impressive, with an annual growth rate of over 10% for the past 5 years, according to the Ministry of Culture and Tourism of the People's Republic of China. The traffic congestion has attracted the attention of academia and the Government (Albalate and Bel 2010; Cuccia and Rizzo 2011). In particular, severe congestion on highways during national holidays has been a frequent headline with rapid motorization. The construction of HSR has extended the tourist market. For example, the number of tourists visiting the famous historical city of Shaoxing, with three world heritage sites, reached 100 million in 2017. Our survey shows that the average distance of visitors to Shaoxing city has increased from 304 km to 473 km, reflecting the much enlarged tourist market after the launch of HSR in 2013. Moreover, 30% of tourists traveled by HSR to Shaoxing. Despite the sharp rise in motorization, the opening of HSR resulted in a 6.7% reduction in the use of cars to travel to Shaoxing. An improvement in the ticketing system for family and other tourist service packages may further increase the use of HSR.

According to previous studies, rail allows more efficient use of land for transportation than highways and helps cut pollution compared with automobiles (Wee et al. 2005). Because of the scarcity of land and the high population density, the PRC is seeking to make efficient use of land and reduce pollution by promoting rail use. Since early signs suggested that rail could become more attractive than civil aviation or automobiles with the rise in income and the growth of the economy, the PRC has been planning HSR construction since the 1990s.

2. HSR NETWORK PLANNING AND CONSTRUCTION

In the PRC, the construction of HSR started at the beginning of the 21st century. The Qinhuangdao–Shenyang line, with a top speed of 200 km per hour, was started in October 2003 and has been the cornerstone of the HSR age. To speed up the rail development, the state council executive passed the "Mid-term and Long-Term Railway Network Plan" in January 2004. It was revised in 2008 (NDRC 2008), then in 2016, expanding the national railway program to create over 150,000 km of national railway by 2020, with over 30,000 km of HSR (NDRC 2016). It also decided that the inter-city HSR should cover the main cities in economically developed and densely populated areas, like the Yangtze River Delta, the Pearl River Delta, and the Shandong Peninsula. By January 2018, the HSR development had reached 25,000 km (Figure 4). The 109,600 square km Yangtze River Delta is one of the most developed areas in the PRC, with 20% of the national GDP output and a high urbanization rate. The construction of the HSR network will cover four city centers—Shanghai, Nanjing, Hangzhou, and Hefei.

Figure 4: Expansion of HSR in the PRC
(km)



Source: Ministry of Transport of the PRC. 2003–2017.

The system is designed for a one–two-hour "traffic circle" between major cities and their adjacent cities, with transfers allowing passengers to arrive at all other cities in the delta within three hours. Such a network could allow these four cities and their smaller counterparts to function as a single integrated urban mega region. During the last decades, the PRC has constructed 16 railway lines, including the Hefei–Nanjing line, the Zhengzhou–Xuzhou line, and the Quzhou–Jiujiang line (Table 1). To allow the fast construction of HSR, it has planned many HSR stations, like Quzhou Railway Station and Xuzhou East Railway Station, in suburban locations away from city centers.

Table 1: HSR Line in the Yangtze River Delta

No.	Name of HSR Line	Number of Stations Passed	Designed Speed	Length	Start from
1.	Quzhou–Jiujiang	10	200 km/h	334 km	Dec 2017
2.	Zhengzhou–Xuzhou	9	350 km/h	362 km	Sep 2016
3.	Jinhua–Wenzhou	7	200 km/h Highest 250 km/h	189 km	Dec 2015
4.	Nanjing–Anqing	14	250 km/h	257 km	Dec 2015
5.	Hefei–Fuzhou	21	350 km/h	813 km	Jun 2015
6.	Hangzhou–Changsha	21	350 km/h	921 km	Sep 2014
7.	Nanjing–Hangzhou	11	350 km/h	249 km	Jul 2013
8.	Hangzhou–Ningbo	7	300 km/h Highest 350 km/h	152 km	Jul 2013
9.	Hefei–Bengbu	9	350 km/h	131 km	Oct 2012
10.	Beijing–Shanghai	24	380 km/h	1,318 km	Jun 2011
11.	Shanghai–Hangzhou	9	300 km/h	165 km	Oct 2010
12.	Shanghai–Nanjing	22	300 km/h	301 km	Jul 2010
13.	Ningbo–Taizhou–Wenzhou	12	250 km/h	275 km	Sep 2009
14.	Wenzhou–Fuzhou	13	250 km/h	298 km	Sep 2009
15.	Hefei–Wuhan (planned)	13	250 km/h Highest 300 km/h	360 km	Apr 2009
16.	Hefei–Nanjing	7	250 km/h	156 km	Apr 2008

Source: Authors.

In 2009, the National Development and Reform Commission also passed the "Inter-city Rail Transportation Network Plan for the Pearl River Delta Region (Revision)." The rail network proposed in the plan comprised 23 lines with a total length of 1,890 km, reaching a network density of 4.8 km of rail per million sq km of land by 2030 (NDRC 2009). Among the 23 lines, the construction of 15 will take place by 2020. The network design comprises three rings and eight axes and will link nine cities of the Pearl River Delta region and extend to other parts of Guangdong province; Hong Kong, China; and Macau, China. By February 2018, the total rail length in Guangzhou reached 4,510 km. Of this, 1,542 km could allow HSR with speeds of 200 km per hour and higher.

3. HSR STATION LOCATION

In the PRC, the "HSR new town" model has dominated the government planning in the site selection for HSR stations. In this model, most new station sites are located in suburbs or exurbs away from the large urban centers. The hope is that HRS stations will trigger the development of new towns. (In Western terms, these would be major metropolitan sub-centers or districts.) The plan is to stimulate local economic development by offering an attractive alternative location to the crowded city centers.

Take the example of the 1,318 km Beijing–Shanghai HSR line. Of the 24 cities connected by the line, 18 chose to build HSR stations in suburbs. The reasons for suburban site selection included ensuring lower costs, capturing rising land values, and relieving pressure on the central areas of the cities. Since there is less densely developed land in suburbs, it is possible to reduce the cost of land acquisition compared with that in city centers. Suburban station development may also generate land value increment profits due to positive spillover effects. Finally, many cities are interested in promoting the transformation of the urban spatial structure from a single center into a polycentric structure to alleviate the pressures of high population density and intense commercial activity in the central cities.

The railway authorities also want to locate HSR stations in suburbs. This simplifies HSR track alignment, allowing straight lines that reduce the project construction costs as well as the operation costs of HSR. Their preference for suburbs may be compounded, as the railway authorities are not responsible for the connecting transport for passengers accessing stations.

In addition, the location of HSR stations varies according to the influence of the local government in the cities through which it passes or provides a station. Because of the PRC's hierarchical administrative system, large cities are more influential in controlling negotiations between the local government and the railway authority than smaller cities. Thus, in mega cities, most HSR sites are located in suburbs, while, in most medium and small cities, new stations are located in the exurban fringe (shown in Table 2), where it is difficult to provide a good public transport service. Hence, smaller cities have greater local car traffic associated with stations.

Shanghai Hongqiao HSR station is a typical example. The station is part of the Hongqiao Integrated Transport Hub (Figure 5), which includes an international airport and Hongqiao business zone. The Hongqiao area plan is intended to guide development in the vicinity of the transport hub. The station is located 15 km from Shanghai city center (Figure 6) and links the Beijing–Shanghai HSR with the Beijing–Shanghai railway and the Shanghai–Nanjing intercity railway to the north and the Shanghai–Kunming railway, the Shanghai–Hangzhou–Ningbo passenger dedicated line, and the Shanghai–Hangzhou inter-city railway to the south. It started on 1 July 2010 with predicted yearly dispatch passenger traffic of 120–140 million in 2020. The daily

passenger dispatch volume reached 169,800 in 2017, double the number in 2011 (68,800 passengers per day).

Table 2: The PRC's Major HSR Station Site Locations and Rail Line Plans

Names of HSR Station	Start from	Number of Metro Lines (at Present)	Location of Station	Linear Distance from the Center	Operation Situation of Metro Lines
North Xian Station	Jan. 2011	0	Suburban	13 km	Line 4: not opened Line 13: not opened
East Zhengzhou Station	Sep. 2012	1	Suburban	8 km	Line 1: Dec. 2013 Line 5: not opened
East Hangzhou Station	June 2013	2	Suburban	13 km	Line 1: Nov. 2012 Line 4: Jan. 2018 Line 6: not opened
Shanghai Hongqiao Station	July 2010	3	Suburban	15 km	Line 2: June 2000 Line 10: Apr. 2010 Line 17: Dec. 2017
South Guangzhou Station	Jan. 2010	2	Suburban	18 km	Line 2: Sep. 2010 Line 7: Dec. 2016 Line 22: not opened Foshan Line 2: not opened
South Nanjing Station	June 2011	4	Suburban	10 km	Line 1: June 2011 Line 3: Apr. 2015 Line S1: July 2014 Line S3: Dec. 2017 Line 6: not opened
South Beijing Station	Aug. 2008	2	Near city center	6 km	Line 4: Sep. 2009 Line 14: Dec. 2015
West Jinan Station	June 2011	1	Suburban	12.5 km	Line 1: Jan. 2019 Line 3: not opened Line R1: not opened
Wuhan Station	Dec. 2009	1	Suburban	10 km (to sub-center)	Line 4: Dec. 2014 Line 5: not opened
Tianjin Station	Aug. 2008	3	City center	1 km	Line 2: July 2012 Line 3: Oct. 2012 Line 9: Oct. 2012
South Changha Station	Dec. 2009	2	Suburban	10 km	Line 2: May 2016 Maglev Line: May 2016 Line 4: not opened

Source: Collected by the authors.

Newly constructed expressway networks and rail transit networks enhance the connection between Shanghai city center and the Yangtze River Delta region through the station. So far, the rail transit lines (including line 2, line 10, and line 17) that provide seamless transfer from Shanghai city center extend to the station (Figure 7).

Figure 5: Hongqiao Integrated Transport Hub Project

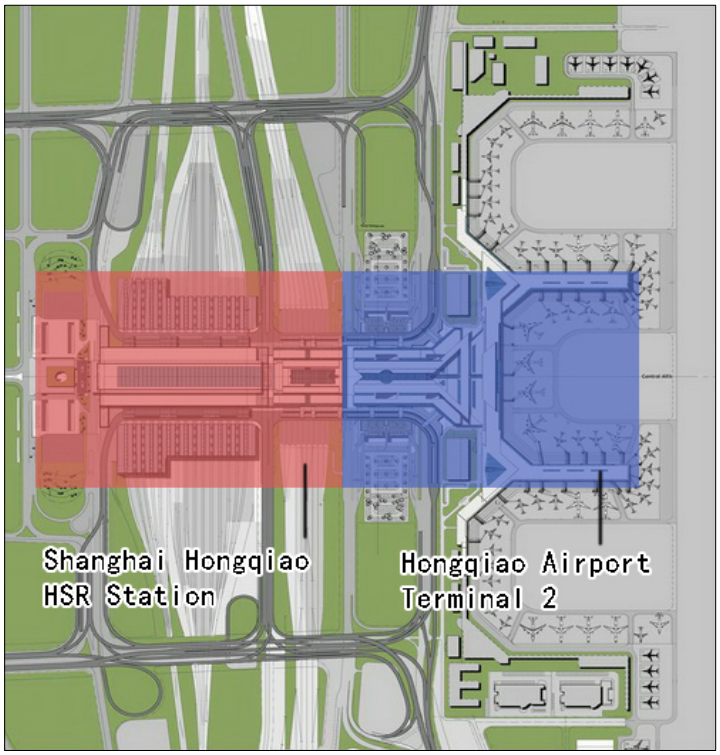


Figure 6: Location of Hongqiao HSR Station and its Transport Connections

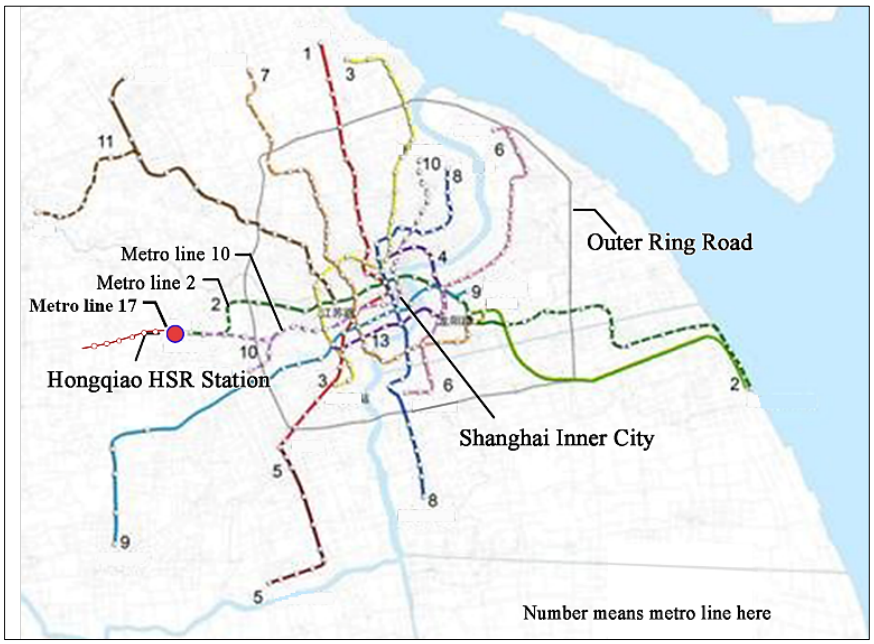
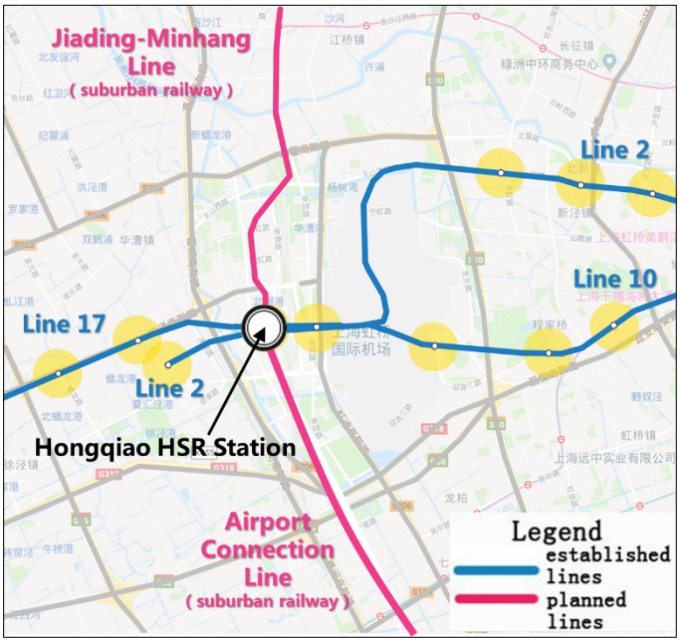


Figure 7: Hongqiao HSR Station and Metro Connection



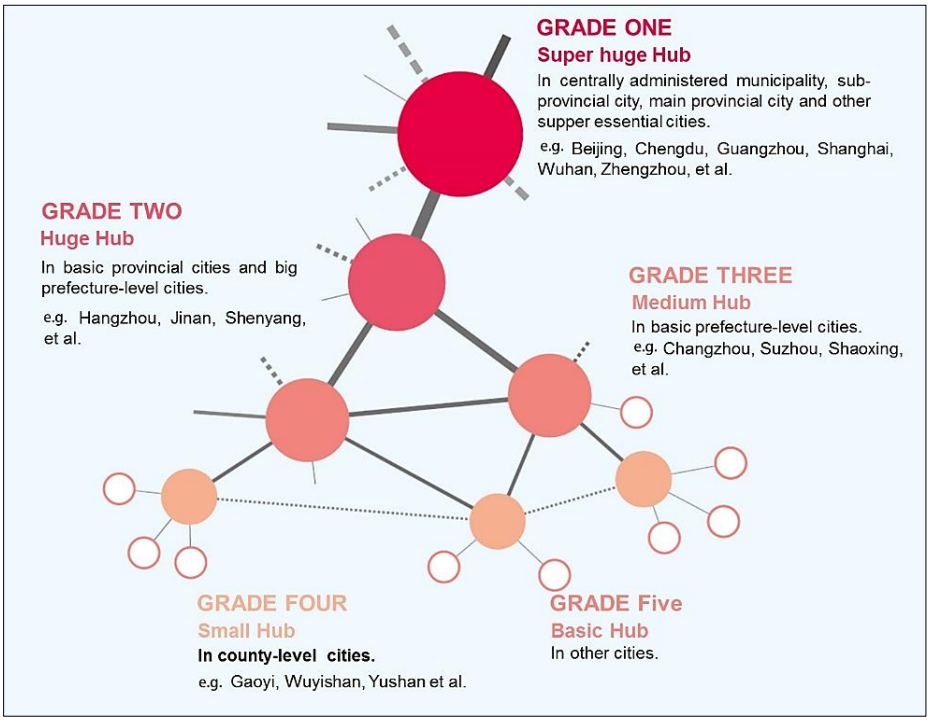
4. HIGH-SPEED RAIL STATION DESIGN AND SERVICES

The development of HSR has involved the construction of a large number of stations. Stadium-sized stations act as city landmarks, with a well-designed exterior, high-standard construction, and the latest facilities. According to the Asian Development Bank (2015), the rail stations in the PRC can be divided into five types—super, large, medium, small, and basic hubs—based on the local governments' plans and their roles. For hubs with different grades and roles, the facilities and services can be different (Figure 8). For instance, Guangzhou South Railway station, 17 km south of the downtown area, is 500 meters long and 450 meters wide, with a covered area of 486,000 sq meters.

A multi-level infrastructure can integrate multiple modes of transport, like cars, public transit, metros, taxies, and inter-city buses, into the station. Since the traffic volume is high on national holidays, a large square appears in front of the railway station. For example, Shanghai Hongqiao Railway Station is connected to the city center through two rail transit lines, an elevated motorway, and several bus lanes.

HSR stations also have large parking lots. According to the *Code for Urban Parking Plan* (GB/T 51149-2016—the standard parking plan in the PRC), all rail stations should provide one parking space per hundred peak passenger volume. For example, Guangzhou South Railway Station has parking space for 2,300 vehicles. At Shanghai Hongqiao station, there is space for 3,000 vehicles.

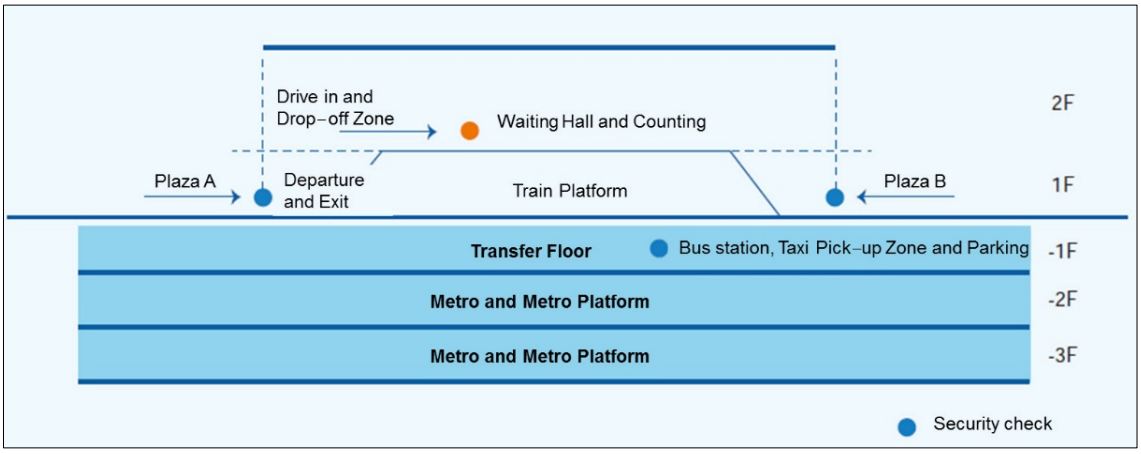
Figure 8: The Grades of HSR Stations in the PRC



Source: Chen et al. (2015).

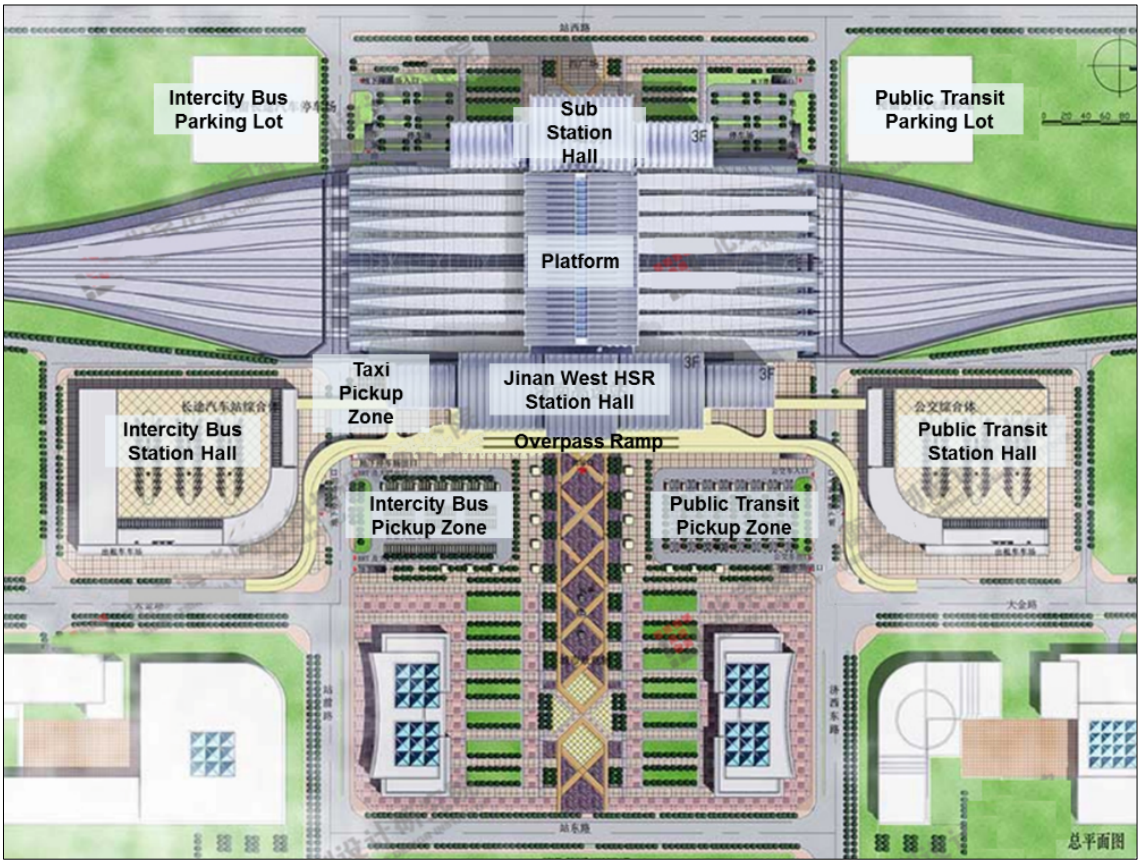
As taxis play an essential role in the passenger flow, the layout of pick-up zones aims to make them convenient for passengers. Usually the pick-up areas are located on both sides of HSR station halls. Inside the station hall, different modes of transport are integrated through various floors, called multi-dimensional traffic organization, as Figure 9 shows. With a waiting hall located on the second floor, passengers arriving by car can enter the station directly from the second floor through an overpass ramp, as Figure 10 shows. However, the exit and arrival areas for passengers are usually located on the same floor as the train platform, while parking lots, taxi pick-up zones, and public transit stations are underground. The metro is located on the second and third floors. Plenty of escalators help to carry streams of passengers.

Figure 9: Integrated Modes of Transport in an HSR Station Hall in the PRC



Source: Chen et al. (2015).

Figure 10: The Overpass Ramp Moving Passengers Directly to the Departing Floor in Jinan West Station



Source: The road network design of the vicinity of Jinan West Station (http://www.thupdi.com).

In terms of HSR service, the departure process is relatively complex, since a passenger needs to take a reserved ticket and pass through a security check before entering the waiting hall for the train. There will be staffs and automatic machines to check their tickets 15 minutes before the departure of the train. Most waiting halls are huge to accommodate the super-peak period rush and are enclosed buildings with proper air conditioning, as Figure 11 shows. Online booking now allows passengers to pay for their ticket through their mobile phone, the Internet, and telephone. HSR stations on certain corridors even allow passengers to board the train directly with their personal ID card, easing the ticket-checking process. However, there is only a flat fare without other package choices (such as family ticket, weekend ticket, or advanced ticket) for passengers.

The HSR service is safe and reliable. Until now, there have been almost no major security lapses, and the punctuality rate is high. Even during the Spring Festival, a period of peak passenger volume, the on-time rate is close to 100%. Any delay is displayed on the huge electronic display screen in the station hall or conveyed through messages on mobile phones. Passengers also receive information about gate numbers to the trains and reserved seats. Even for business travel, HSR is cost-effective. Compared with other countries, the ticket price of Chinese HSR is relatively low, at only 42 RMB per 100 km for second-class travel. Therefore, many people living in cities surrounding a metropolis use HSR to commute. In the city cluster regions, like the Pearl River Delta, the Yangtze River Delta, and Beijing–Tianjin–Hebei, where the economic interaction between cities is strong, the HSR corridor is extremely busy. For example, the departure interval of HSR services from Suzhou to Shanghai during

the morning peak hours is just 5 minutes, and it serves as an urban public transit system. Nevertheless, there are some stations where the HSR service frequency is quite low, like Xianlin Railway Station (in Nanjing), from which there is only one train to Shanghai a day.

Figure 11: The Waiting Hall at Guangzhou South HSR Station

Source: Chen et al. (2015).

5. HIGH-SPEED RAIL AND ACCESS MODE

Since HSR stations are far from the city center, where there is a high demand for travel, the PRC has put considerable effort into improving the transport between the station and the city center, like providing public transit services (bus, metro, or both) simultaneously. In Jiaxing, where the HSR station is 8 km away from the city center, only a bus connects them. According to the survey and analysis by Ye et al. (2017), passengers using taxies and public transit account for over 90% of passengers in big cities. Passengers value time more than expense.

Figure 12 shows the modal split that we observed in a survey at Shanghai Hongqiao Station. We found that 60.4% of passengers accessed HSR by urban rail transit and an additional 7.9% used the conventional bus system, bringing the total users of public transport to access HSR to 74.9%. This is far in excess of the planning forecast share for transit, which was 50%. Of the private transit modes, only 7.6% of passengers take cars to Hongqiao Station, while 14.5% take a taxi. The forecasts for the project predicted considerably higher private transport access.

Figure 12: Modal Split of Transit to Hongqiao HSR Station

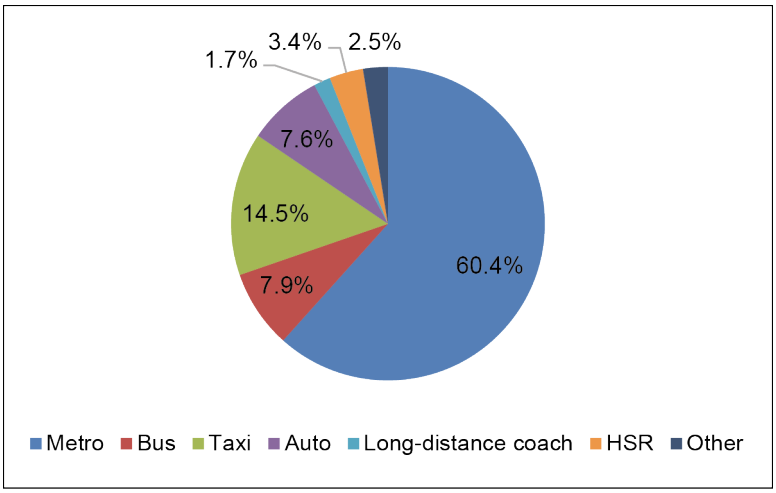
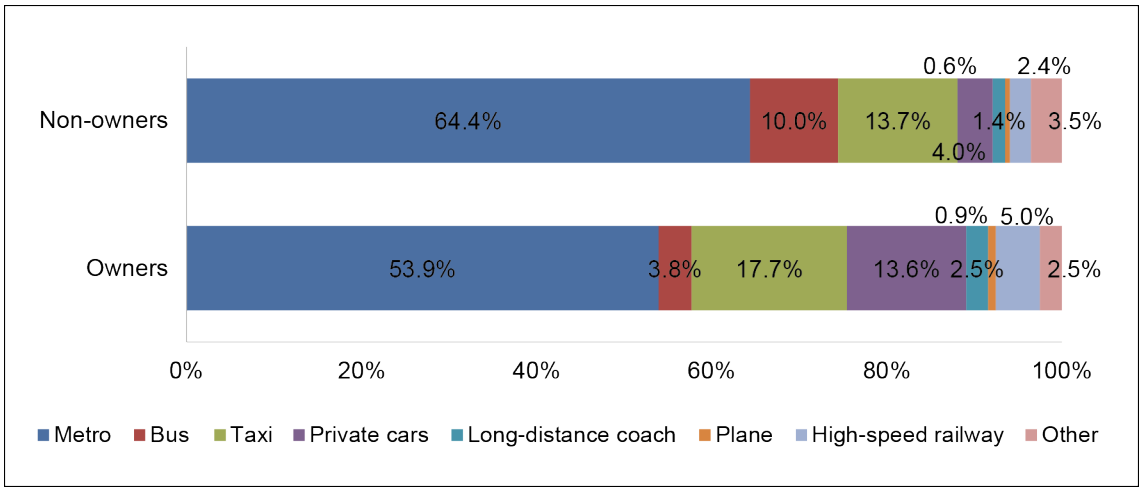


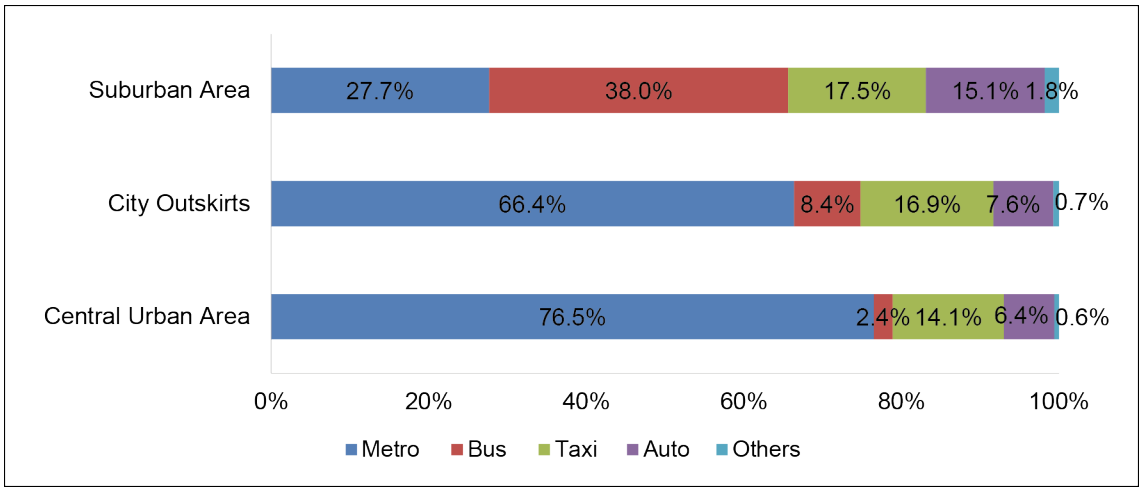
Figure 13 shows the mode of access to HSR stations by car owners and those without a car. Even among HSR users who possess a car, only 13.6% drove to the station. These private car-owning passengers showed a preference for the metro, with 53.9% preferring the metro to travel to the station. Private car-owning passengers use bus transit much less than passengers who do not own a car. These results show the importance of the provision of high-quality public transport for connecting city centers and HSR stations to reduce the demand for car travel. The investment in metros to HSR stations undoubtedly reduced the car mileage to stations located far away from city centers—a boon from the traffic and air pollution perspective.

Figure 13: Station Access Mode Choice of Car Owners and Non-owners



Comparing the modal choice of travel to the HSR station from various districts of Shanghai, we found that 76.5% of passengers from the central urban area take urban rail to the HSR station, while only 7% use cars. For passengers from suburban areas, which are less well served by the urban rail network, people rely more on conventional bus transit, with 38% taking buses to the station and only 27.7% using urban rail. From suburban areas, the demand for travel to the HSR station by car is 15.1%, double that of the central urban area (Figure 14).

Figure 14: Modal Split of Transit to the HSR Station from Different Regions of Shanghai City



To provide a better high-speed train service, HSR now also connects Shanghai Railway Station, located closer to Shanghai city center. People can take public transport, like metro line 1 and metro lines 3 and 4, as well as the normal bus, to the station. Among HSR passengers, 44.6% use the metro, normal buses account for 15.7%, and taxis account for 27.4%.

The survey from Wuchang Railway Station in Wuhan shows that 92% of passengers take other transportation than rail: 20% intercity buses, 26% metros, and 23% city buses (Table 3). To improve the interconnection to public transit systems, the distance is shortened to 70 meters, while the walking distance to other private cars is 166 meters (Chang and Ye 2009).

Table 3: HSR Access Modes at Wuchang Station

Transfer Modes	Proportion
Rail	8%
Intercity Bus	20%
Public Transit	26%
Metro	23%
Taxi	6%
Auto	8%
Others	10%

Source: Chang and Ye (2009).

These results indicate that people who take high-speed trains are more sensitive to time, reliability, and flexibility. There is a need to upgrade urban public transport services along with the construction of HSR, metro, or other facilities to prevent congestion around HSR stations.

6. HSR NEW TOWN PLAN

The PRC cities' local governments expect HSR to boost the city economy and development. There are several plans, like a station area master plan and urban design plan, to guide the construction in the vicinity of HSR stations. For cities like Nanjing and Shanghai, HSR stations provide a prospective zone, a sub-city center, or even a new town, which is called an "HSR new town." Taking Nanjing as an example, the catchment area of Nanjing HSR South New Town is 184 sq km, with a projected population of 1,600,000, which will be one of the three sub-centers of the city following the master plan. Changsha HSR New Town, with 500,000 people, occupies 46.9 sq km. The plan for Jinan West New Town shows the same population but an area of 55 sq km.

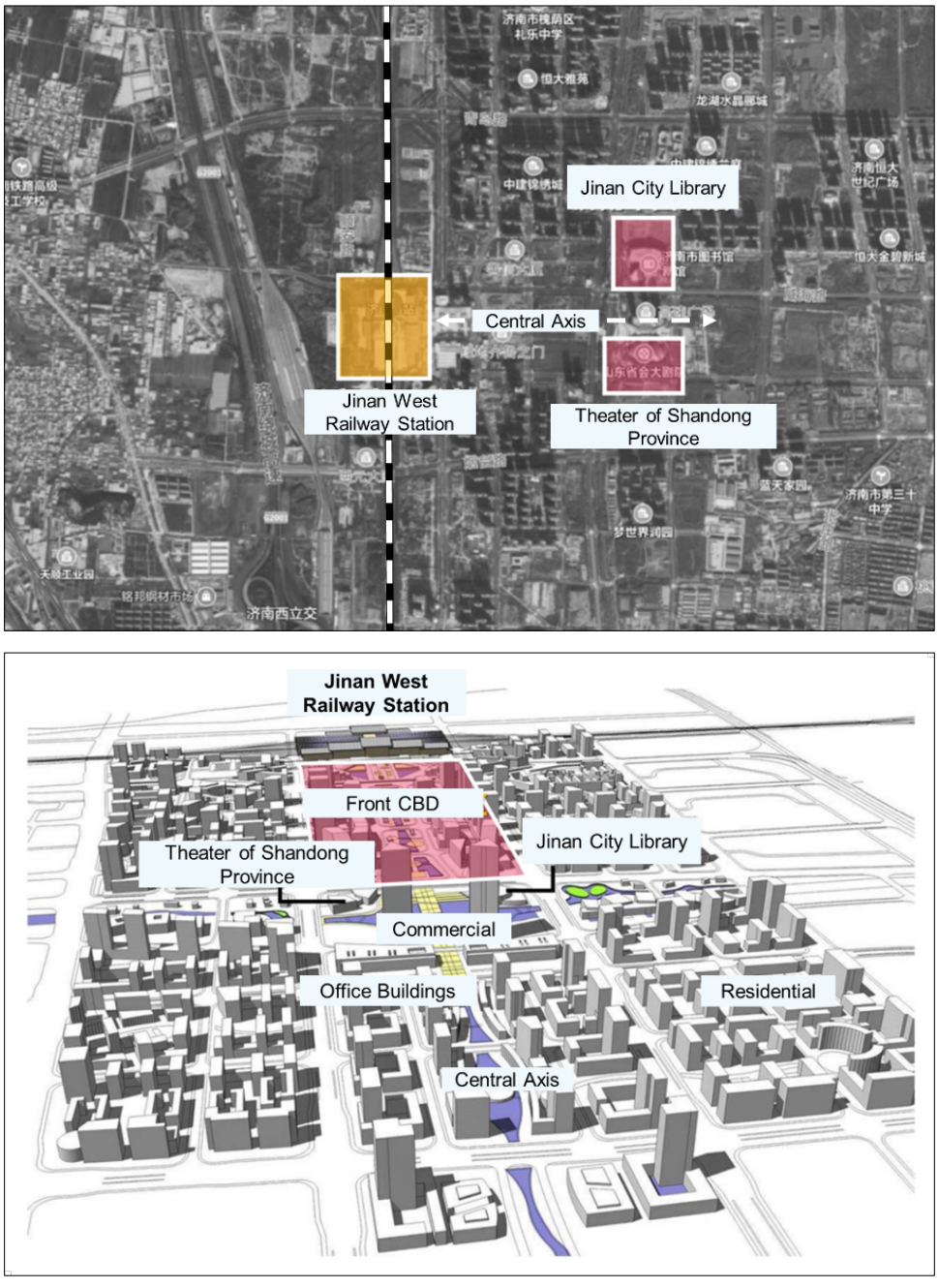
Usually, new clusters of high-rise buildings for businesses, offices, and commercial activities surround HSR stations. Sometimes, public facilities like museums, exhibition centers, and libraries are also located near the station. Figure 15 shows the master plan of the Tianjin West HSR Station area, with an exhibition center, a sports center, and clusters of office and commercial buildings to the north of the station and hotels to the south. The design is for a mixed-used area to attract people to live, work, and entertain.

Figure 15: Master Plan of the Tianjin West HSR Station Area

Source: Liu et al. (2008).

Jinan has built its West Station on green fields. There is an axis in front of the station, with a city library and a theatre on its two sides. The public facilities aim to promote the development of peripheral regions (Figure 16). The city has barely realized this aim in terms of the functions that the plan defines; except the HSR station, many supportive elements do not exist.

Figure 16: Planned Model of the Jinan West HSR Station Area



Source: The road network design in the vicinity of Jinan West Station (http://www.thupdi.com).

7. HSR STATION LOCATION AND TRAVEL EFFICIENCY

As many HSR stations are located far away from city centers, empirical data are necessary to analyze their impact on the travel characteristics of passengers and the urban spatial structure, including the travel distance distribution, changes in travel time, and HSR passenger distribution in different geographic locations. This information will be useful in improving the travel efficiency of inter-city HSR services through the station location or connecting transport service options as well as the design of stations.

We conducted a survey of 1,834 respondents from 27 February 2012 to 3 March 2012 at Hongqiao HSR Station. Passengers in the waiting hall were selected randomly for face-to-face interviews and asked about their trip origin and destination, on-board HSR travel time, mode of travel to the HSR station and travel time to the station, and demographic characteristics.

From this survey, we learned about passengers' social and economic attributes. We also collected information for each segment of their travel—from origin to destination—and their travel characteristics before and after the opening of the HSR station. Based on these data, we can analyze the impact of the location of HSR stations and the connecting transport system on the travel efficiency for HSR passengers in terms of time and cost. We can also compare the actual findings with transit planners' forecasts made in preparation for the development of HSR services and stations. The following research questions are explored in this study:

(i) How far will passengers travel by HSR and which factors will influence the passenger volume between Shanghai and a destination city?

(ii) Where do the passengers traveling to Shanghai originate? As the location of the station is closer to neighboring provinces of Zhejiang and Jiangsu, how many passengers are from regions outside Shanghai?

(iii) What is the proportion of time spent in each segment of travel and how can we improve travel efficiency?

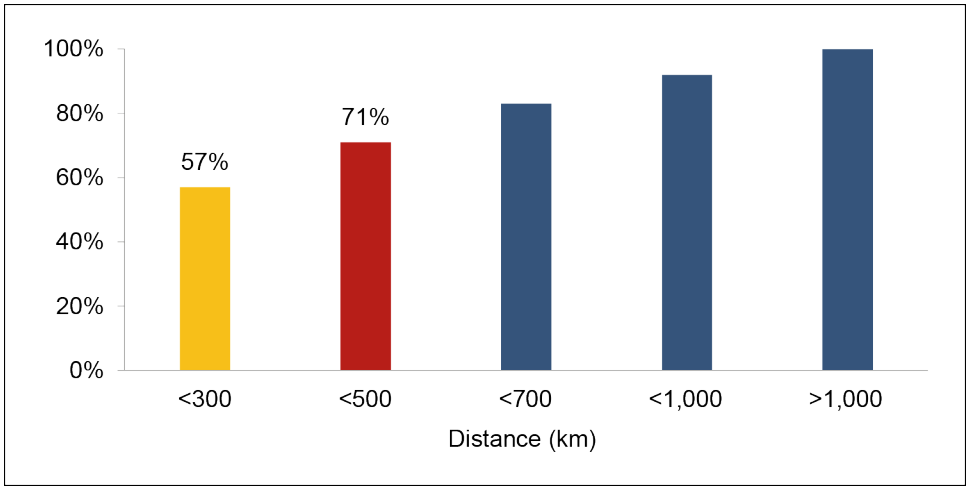
The PRC covers a vast geographical territory, and the construction of a national HSR network will facilitate inter-regional connections. How are passengers distributed from Hongqiao Station to their destinations? Conducting a regression analysis based on the variables of passenger numbers, the population of the destination city, and the distance between Shanghai and that city, we found that the number of passengers is in direct proportion to the destination city's population but in inverse proportion to the distance between Shanghai and the city (Table 4). In other words, the larger the population of the destination city, the more passengers travel from Shanghai to the destination city; the shorter the distance to the destination city, the more the passengers travel via HSR.

Table 4: The Number of Passengers as a Function of the City Population and Distance

Model	B	t	Sig.
(Constant)	1	2.71	.015
City Population (0,000)	.086	2.76	.013
Distance (km)	–0.125	–3.01	.008

The research reveals that the average passenger travel distance is 377.4 km, which is not as far as the expectation before the opening of HSR indicated. It can be concluded from the travel distance distribution that short- and medium-distance passengers still comprise the majority of HSR travel, with 57% of them traveling less than 300 km and 71% traveling less than 500 km (Figure 17).

Figure 17: Cumulative Percentage of Travelers



From Table 5, we can see that 88% of the passengers surveyed are from different districts in Shanghai, 4.1% transferring from the nearby Hongqiao Airport and 7.8% from outside Shanghai.

Table 5: The Origin of Surveyed Passengers at Hongqiao HSR Station

	Passengers	Percentage
Hongqiao Airport transfer	75	4.1%
Within Shanghai	1595	88.1%
Outside Shanghai	141	7.8%

To analyze the geographic location of passengers from Shanghai, we divided 16 districts and one county in Shanghai into three major categories—the central urban area, the city outskirts, and the outer suburban districts (Table 6 and Figure 18).

Table 6: Administrative Districts' Distribution in Shanghai

Location	District Name	
The central urban area	Hunagpu district	Hongkou district
	Zhabei district	Changning district
	Jing'an district	Yangpu district
	Xuhui district	Putuo district
The city outskirts	Baoshan district	Pudong new area
	Jiading district	Minhang district
Outer suburban districts	Chongming district	Songjiang district
	Fengxian district	Qingpu district
	Jinshan district	

Figure 18: Shanghai District and County Administrative Divisions

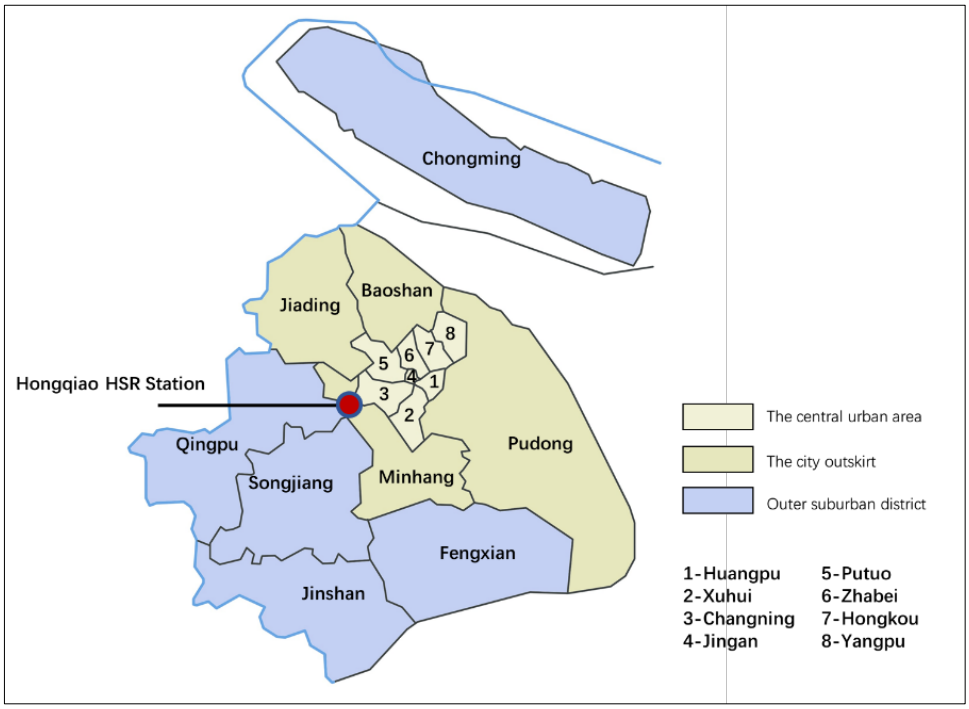
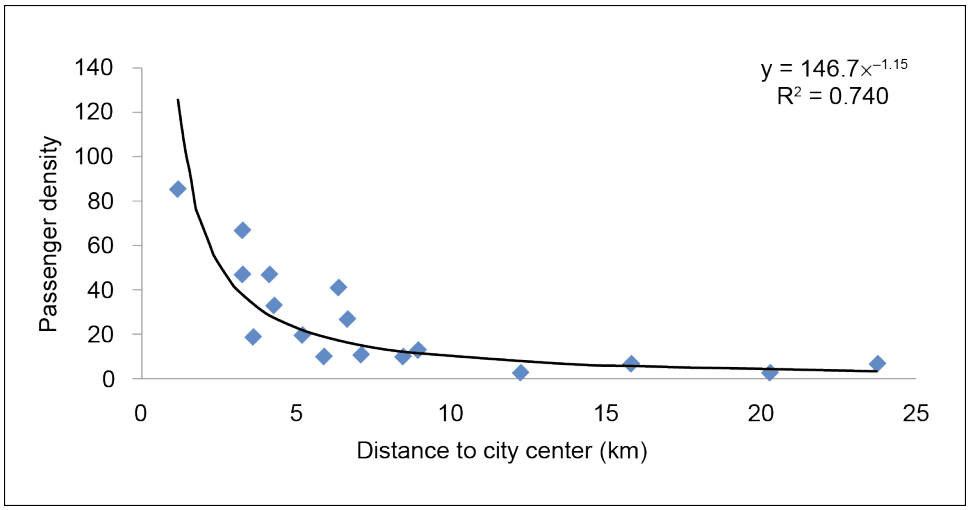


Table 5 reveals that approximately half of HSR passengers come from the central urban area of Shanghai, 40% from the city outskirts, and only 10% from the outer suburban areas. Further analysis of the passenger intensity from various administrative districts of Shanghai (where intensity is the number of passengers divided by the population of the district) shows that the passenger intensity is in inverse proportion to the distance to the central urban area (Figure 19). In other words, the majority of passengers come primarily from the dense central urban areas and adjacent districts. Thus, an HSR station located in the suburbs will require the majority of passengers to travel extra distance.

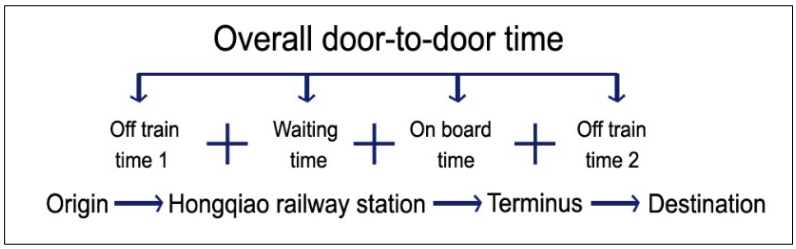
Figure 19: The Relationship between the Density of HSR Passengers and the Distance to the City Center



As Figure 20 illustrates, the total door-to-door travel time for HSR comprises four parts—the time from the origin to Hongqiao HSR Station, the waiting time at the station, the

travel time on board the HSR service, and the time from the destination HSR station to the point of destination.

Figure 20: The Segments of Door-to-Door Travel Time Consumption



As the speed of HSR is high, the on-board time between two stations is greatly reduced compared with traditional rail or highway transit. However, if people travel a relatively short distance, the on-board time may comprise only a small portion of the total travel time. In this sense, during the planning and construction of HSR, it is necessary to pay attention to the access modes serving HSR stations. A large improvement in travel efficiency through HSR is only realizable when the connecting travel time from the origin to the HSR station and the egress time to the travel end point can be kept down in proportion to the overall travel time. If the planning does not account for this, the increasing train speed may make a limited contribution to the total travel efficiency.

From our survey, it is apparent that the average on-board HSR travel time is 192 minutes, accounts for 55.7% of the total travel time, and the transit time to HSR Hongqiao Station is 56 minutes, and the waiting time for the HSR train 61 minutes (Figure 21). For shorter trips under 300 km, the on-board travel time for HSR only accounts for 25% of the total travel time, as shows in Figure 22. Thus, for shorter trips, the higher train speed will produce less benefit in improving travel efficiency, and efforts during HSR planning to reduce the off-train time are really the key.

Figure 21: Total Passengers' Door-to-Door Time Composition

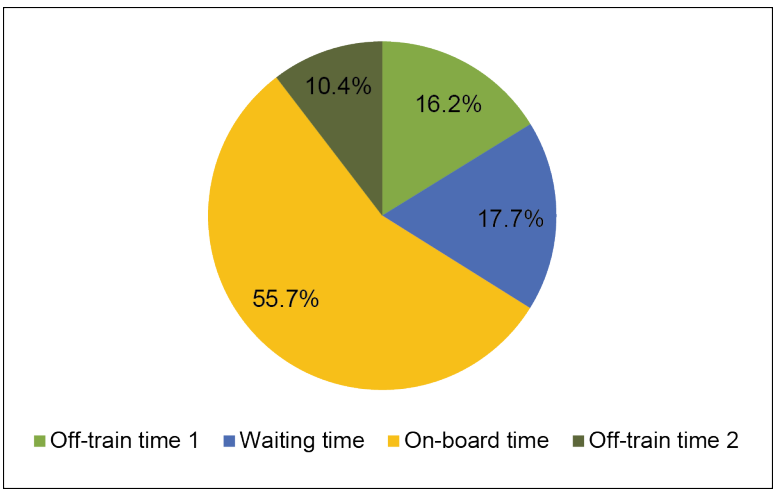


Figure 22: The Off-Train Time as a Percentage of the Total Travel Time Compared with the On-Train Travel Time

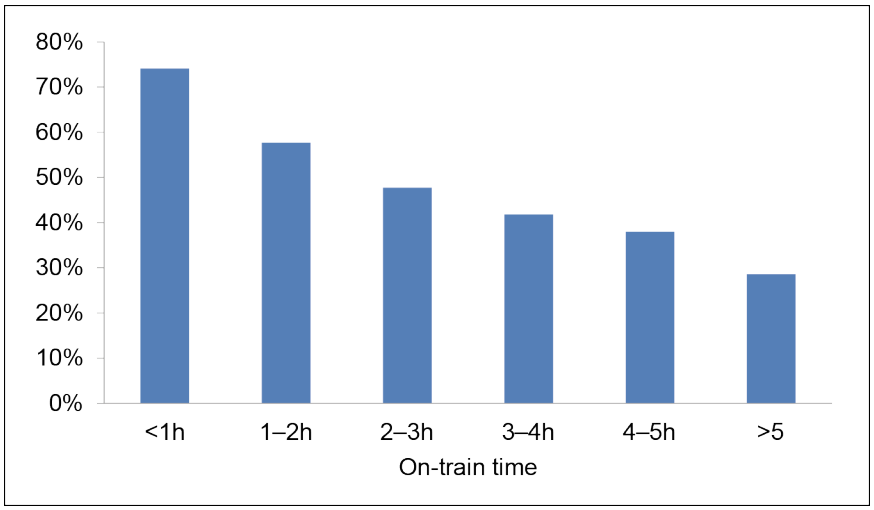


Table 7: Access Time Changes in Different Districts of Shanghai

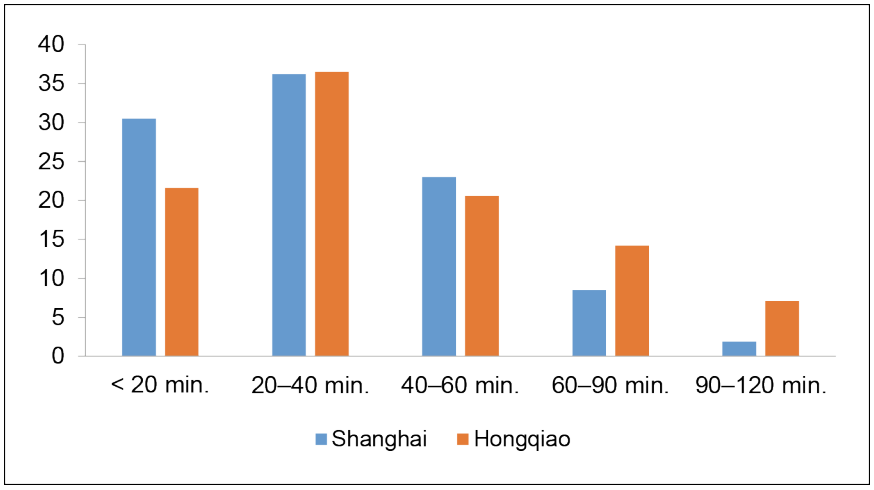
	District	Average Access Time to Hongqiao HSR Station (min.)	Average Access Time to Shanghai or Shanghai South Railway Stations (min.)	% Change
Central Urban Area	Jingan	40	36	11.1%
	Huangpu	46	37	24.3%
	Hongkou	46	40	15.0%
	Yangpu	70	54	29.6%
	Zhabei	50	33	51.5%
	Putuo	44	43	2.3%
	Xuhui	40	41	–2.4%
	Changning	27	41	–34.1%
City Outskirts	Baoshan	66	52	26.9%
	Pudong	61	49	24.5%
	Minghang	46	47	–2.1%
	Jiading	51	67	–23.9%
Outer Suburban Area	Songjiang	61	72	–15.3%
	Qingpu	47	73	–35.6%
	Jinshan	78	97	–19.6%
	Fengxian	70	61	14.8%
	Chongming	147	118	24.6%

Before the opening of Hongqiao HSR Station, people could take traditional or high-speed trains at either Shanghai Railway Station or Shanghai South Railway Station, both of which are located quite close to the city center. Comparing passengers' average access time to those two stations with the average access time to the newly built Hongqiao HSR Station, we found that the average access time has increased by 18%, from 50 minutes to 59 minutes (Table 7). The passengers whose access time has increased the most are those whose origin is the central urban district. Passengers in the suburban southern part of Shanghai benefit from the location of Hongqiao HSR Station in the form of reduced access time to the station. However, the passenger intensity is relatively low there. The large-scale expansion of the Shanghai urban rail

system over the past several years has partially mitigated the effects of having an HSR connection located farther away, and it appears that the travel time increase is acceptable to most passengers.

After the opening of the HSR service in Shanghai, one study has compared the access time to the two stations, showing that the access time to Hongqiao HSR is longer than that to Shanghai Railway Station (Figure 23). People will also pay 3 RMB more to travel to Hongqiao HSR station on average.

Figure 23: Comparing the Access Time to Hongqiao HSR Station and Shanghai Railway Station



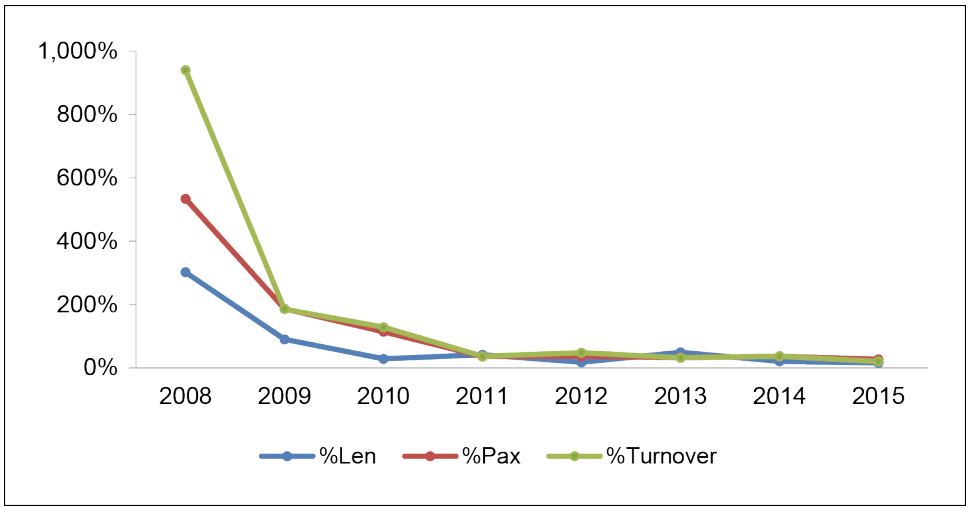
8. HSR PASSENGER AND ECONOMIC IMPACT

The large-scale HSR network and service has attracted a large number of passengers. In 2008, passengers taking HSR accounted for only 0.5% of the total railway passengers in the PRC. In 2016, 43.4% of railway passengers traveled by HSR. In 2012, the PRC built around 10,000 km of HSR. From that year, the increase in passenger and passenger-km became more stable (Figure 24).

The economic impact of investment in transport has been the subject of a long debate. Jia and Qin (2014) categorized the research on the economic impact of HSR into three types, the study of the input–output balance, the interaction intensity between cities reflected by a time–space map or other methods, and statistical models to analyze the impact of accessibility on economic changes.

First, increased spending is likely to raise the economic output, whether it is on transport infrastructure or on something else. Recent developments in economic geography have placed particular stress on agglomeration economies as a source of productivity growth. Improving the connectivity between firms and their suppliers, competitors and customers, and existing and potential sources of labor may enable specialization, the exploitation of economies of scale and productivity, and hence increased output. Jia and Qin (2014) suggested that HSR construction should take the passenger demand into consideration to strike a balance between input and output. Therefore, the HSR corridor has to link metropolises with high population density, serious congestion problems, and limited aviation services.

Figure 24: The Growth Rate of the HSR Network Size, Passengers, and Passenger-km



Second, in terms of the location of economic activity, studies have suggested that HSR will tend to benefit core cities rather than the periphery (Puga 2002). The impact of investment in HSR is most likely to concentrate in large business-oriented cities, mainly located in the eastern and the southeastern parts of the PRC, such as Beijing, Tianjin, Shanghai, Wuhan, Changsha, Jinan, Xuzhou, Suzhou, and Guangzhou, as well as provincial capital cities. Today, the more economically advanced HSR corridors, like Beijing–Tianjin, Wuhan–Guangzhou, and Beijing–Shanghai, generate much more traffic than the corridors located in the central and western areas of the PRC. One study (Lu et al. 2013) investigated the spatial distribution patterns of HSR economic zones and showed that the HSR network has replaced the evenly distributed spatial economic model with a clustered distribution and accordingly increased the urban agglomeration effect in metropolitan areas like the Yangtze Delta region. However, there are significant differences in terms of the spatial economic model; for instance, Shanghai and Guangzhou form a radial inflow model, Wuhan and Beijing belong to a "ring-layer" model, and Chongqing presents a centrifugal outflow model. Another study, by Jiang et al. (2017), compared the change of city accessibility on the Harbin–Dalian railway corridor and the Zhengzhou-Xi'an railway corridor. The research showed that, though the accessibility of cities along HSRs has improved, the degree of improvement of the Harbin–Dalian corridor is stronger. Besides, HSR enlarges the accessibility gap of some regions, especially the marginalized ones (Juan et al. 2014).

HSR affects the tourism market in a similar way. According to Yin (2012), the Zhengzhou–Xian HSR corridor has strengthened the tourism attraction of Zhengzhou, Luoyang, and Xi'an and further attracted the tourism industry clustered into these three traditional tourism cities.

However, because of HSR's high cost, some researchers have argued that, in some areas, especially in Western [People's Republic of] China and the poverty-stricken areas in Central [People's Republic of] China, building advanced conventional railways would be preferable. In a country as vast and diverse as the PRC, it is important to take regional differences into account rather than adopting a single approach to rail investment.

9. CONCLUSION

Since 2003, the China Railway Authority has been implementing the national strategic plan for widening railway's reach, prioritizing HSR along with inter-regional cargo rail. The HSR network is now the largest in the world.

HSR is an excellent mode of transport for the PRC's rapidly growing demand for inter-city travel. Its high speed and capacity and its modest land and resource requirements are good for a country with a large territory and many large cities, a dense and increasingly urban population, and serious resource and environmental constraints.

Operating at 350 km per hour, the PRC's HSR is faster than car travel and competitive with domestic air travel for the majority of inter-city trips. It even competes with air travel for journeys of over 1,000 km. Shanghai and many other cities have chosen suburban and exurban HSR station locations because they are less expensive to build, allow straighter alignments and faster rail services, and may stimulate sub-center growth.

Our survey of passengers at Shanghai's Hongqiao Station, a typical new HSR station, showed that over 70% of passengers travel on HSR for distances of less than 500 km. For these travelers, the time taken to access the HSR station is a major consideration; the higher train speed makes a decreasing contribution to total travel efficiency. Therefore, the challenge is to balance the location of HSR stations with the provision of improved urban center transit connections and higher HSR passenger intensity. The Shanghai case shows that extending connections, especially rail transit connections, to the HSR station can attract many passengers. However, this comes at a high cost, and HSR access still takes more time for travelers than the earlier system. In-city stations are also required.

Instead of constructing a large HSR station in a distant suburb, planners should consider the direct connection of HSR to the existing traditional rail stations, where the access to HSR trains can be easier in the passenger-intensive urban areas. This will simultaneously decrease road transportation and thus air pollution and road infrastructure costs. The overall efficiency and benefit to society may be greater. With the introduction of HSR services for intercity travel, we cannot neglect the need to improve the high-quality public transport system within a city. HSR passengers would prefer reliable and comfortable access modes to HSR stations. An HSR service with a poor urban public transport service will induce more car traffic to access the station, resulting in severe traffic congestion or parking problems.

The high concentration of HSR passenger traffic in economically dense areas indicates that HSR is a justified solution for increasing the capacity in those areas. In less developed areas, more sophisticated operation is necessary to balance the relative traffic volume, the operation/maintenance cost, and the political equity policy. Upgrading the normal train service is also required in the less developed areas in the PRC.

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