The Impact of HSR on Same-Day Intercity Mobility: Evidence from the Yangtze River Delta Region

Haixiao Pan, Ya Gao, and Khandker Nurul Habib

Abstract One objective of China's High-speed rail (HSR) development is to promote regional cohesion, which can be reflected by the flow of people between city pairs. As a fast-speed intercity transport mode, same-day intercity mobility has been regarded as an essential measurement for regional cohesion and transport integration. The reduced time by HSR has redefined the business and commute trips which highlights time efficiency. Due to the difficulty in obtaining large samples of data for such trips, we adopted mobile phone data to detect and analyze the spatial distribution and travel behaviour characteristics of same-day return travellers. The efficiency analysis measured by total travel time between city pairs indicates that HSR is less competitive with cars within 300 km for same-day return trips. The variance in HSR passengers' travel time over the same distances could be due to no direct services and the time required for access/egress. Using a 20-week mobile phone data, we adopted a rule-based method for detecting intercity travellers based on their temporal and spatial geographic locations. Results showed that most travellers travelled within 3–3.5 h, and few conducted a same-day return trip regularly. GDP, service frequency, and distance between origin and destination have been examined to explain the mobility of same-day return travel. The findings of our paper are expected to improve our understanding of same-day return travel behaviour and promote HSR travel for efficient round trips.

Keywords High-speed rail · Same-day trips · Intercity mobility · Mobile phone data · China

H. Pan · Y. Gao (✉)
Department of Urban Planning, Tongji University, 1239 Siping Road, Shanghai 200020, China
e-mail: gaoya@tongji.edu.cn

H. Pan
e-mail: panhaixiao@tongji.edu.cn

Y. Gao · K. N. Habib
Department of Civil & Mineral Engineering, University of Toronto, 35 St. George Street, Toronto, ON M5S 1A4, Canada
e-mail: khandker.nurulhabib@utoronto.ca

F. Pagliara (ed.), *Socioeconomic Impacts of High-Speed Rail Systems*,
Springer Proceedings in Business and Economics,
https://doi.org/10.1007/978-3-031-26340-8_4

1 Introduction

Since the first High-speed rail (HSR) launched in China in 2008, the network has noticeably expanded in the past fifteen years. In total, 41,000 km of HSR service length have been operated to connect cities across the country by 2022. In agglomerated regions, such as the Yangtze River Delta (YRD) Region and the Pearl River Delta (PRD) region, the increased density and service frequency of HSR has facilitated the intensity of economic activities. Three types of trips in terms of travel time and travel purposes have been identified in previous research: commuting trips within 1 h, same-day business/tourism trips within 2–3 h, and occasional trips [1, 2]. Among the three types, trips that can be completed within a day are key to regional cohesion and therefore receive tremendous attention from researchers [3–5].

Same-day intercity mobility is generally defined as the ability to complete an intercity around-trip travel within a day. Researchers have adopted location- or schedule-based approaches to measuring same-day intercity accessibility and efficiency [3, 4, 6]. Those approaches mainly evaluate the same-day return travel from the supply side. It is partly due to the lack of revealed data for such trips, either unavailable or conveniently obtainable.

Recently, there has been growing interest in using mobile phone data or other user location data for large-scale mobility behaviour analysis [7, 8]. The mobile phone data can provide the almost real-time anonymized geolocation information to reveal the spatial dynamics of intercity mobility flow. Also, obtaining panel data within a certain period is relatively convenient, from which the periodic travel characteristics of travellers can be detected.

Our objective is threefold in this study: (1) from the supply perspective: we aim to identify the efficiency of possible same-day return city pairs within the YRD region based on the total travel time of both HSR and other competitive modes; (2) from the demand side, using mobile phone data, we try to detect the same-day intercity travellers, and analyze their periodical travel behaviour and spatial distribution characteristics; (3) We attempt to reveal where and to what extent the intercity same-day travel via rail is occurring based on identified rail users passing through the selected railway station areas. The findings of this study are expected to improve our understanding of same-day return travellers and to promote HSR efficiency to support the same-day return travel demand of intercity travellers.

2 HSR in the Yangtze River Delta Region

The Yangtze River Delta (YRD) region consists of Shanghai city and three provincial administration areas (Jiangsu, Zhejiang, and Anhui) (Fig. 1). It is one of the most populous and active regions in China, with 235 million inhabitants in the 2020 census. HSR operation in the YRD region began by connecting major cities, such as Shanghai,

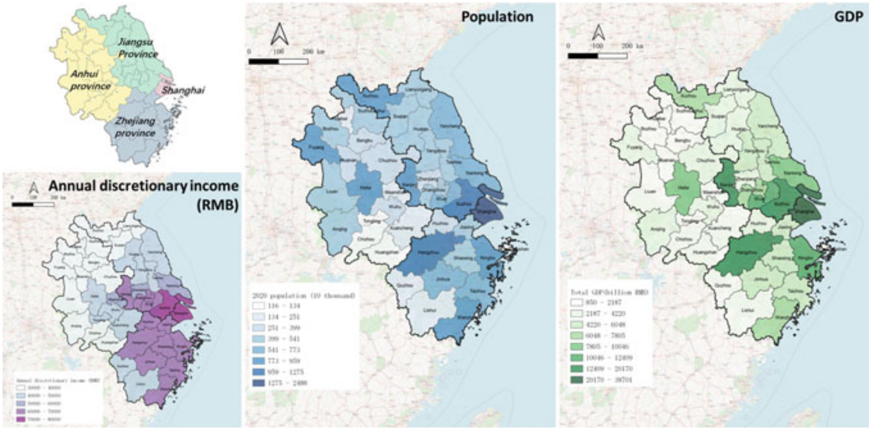

Fig. 1 Population, GDP and discretionary income of 41 cities within the Yangtze River Delta Region by the end of 2020

Nanjing, and Hangzhou, when the passenger volume of existing conventional rail and travel time costs once restricted the regional interaction.

For the past decade, the High-speed rail network has expanded to encompass almost all cities (40 out of 41) within the region. The operated HSR lines have reached 5977 km by the end of 2020 (Fig. 2). The increase in rail mileage for the past decade mainly resulted from the HSR lines. In the next fifteen years, new HSR lines (travelled at 250–350 km/h) and intercity rail lines (travelled at 120–200 km/h) have been planned in the 2020 YRD Transport Integration Development Plan [9]. The new lines aim to provide direct services without transfers, add capacity to congested corridors and connect small and medium-sized cities along the corridors (Fig. 3). The city of Zhoushan, separated by the sea from other cities, is expected to connect to the region's HSR network by 2026.

As a fast-speed intercity transport mode, the time savings by HSR has boosted mobility between cities [10], especially along the Shanghai-Nanjing and Shanghai-Hangzhou HSR corridors. On a typical weekday, around 130 trains (including G and D trains) travel from Shanghai to Nanjing, a 300 km distance with a minimum 59-min in-vehicle time. A similar service frequency operated between Shanghai and Hangzhou, 180 km, with a minimum of 45-min in-vehicle times. New travel patterns, including intercity commuting and same-day return business/leisure trips, have been observed along the highly frequent service corridor [11–13].

3 The Efficiency of Same-Day Return City Pairs

Previous research has proposed different approaches to measure daily mobility via HSR. For example, Liu et al. [3] evaluated the daily accessibility of daytime

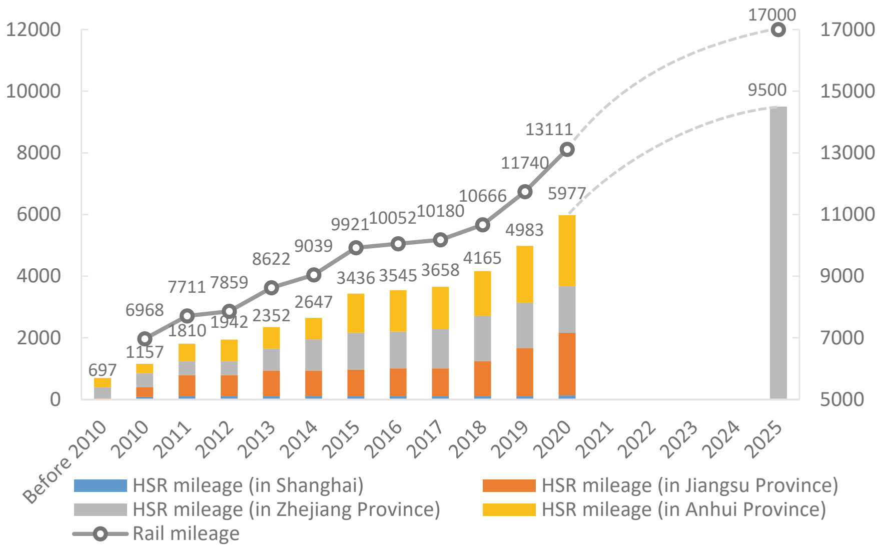

Fig. 2 Shows HSR and total rail mileage within the Yangtze River Delta Region

round-trips in Shandong Province by proposing an improved potential-based daily accessibility index, accounting for GDP, population, area, average travel time, and train frequencies between city pairs. Unlike the previous measurement index, train frequency was added as a weight, and travel time was distinguished into ordinal intervals. They use a threshold of 4 h for one-way business journeys that could be completed within a day. However, the node-based approach (calculating travel time between different HSR stations) did not consider the intra-city travel time, which may account for almost half of the travel time within short travel distances [14]. Thus, the approach proposed may overestimate the cities that could be accessed within a day.

Considering time constraints spent on destination cities and the associated costs for leisure and business same-day return trips, Moyano et al. [4] measured the efficiency of each city-to-city link in the Spanish HSR network. The total population weighted efficiency for tourism travel and the amounts of high-skilled jobs for business travel to obtain the global values of efficiency for comparison. The approach was more precise to capture aggregated efficiency for different travel purposes. However, the approach requires values of time (VOT) parameters obtained by previous research, which is hard to implement without prerequisite information. Also, the above studies only focus on the HSR mode without considering the possible competitive modes for intercity travel, such as cars.

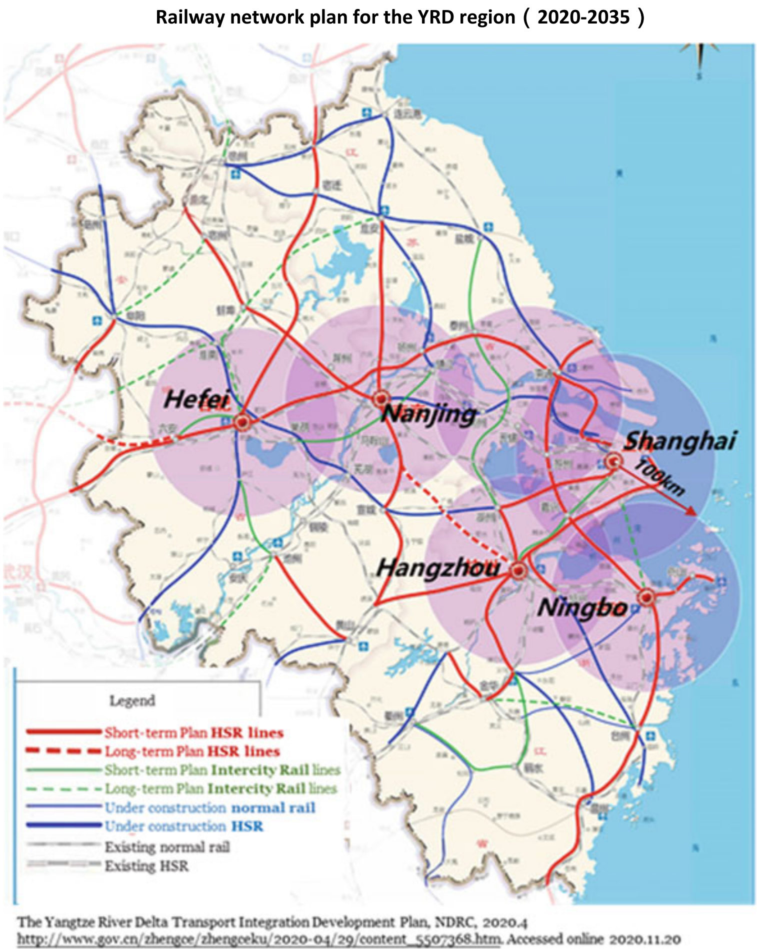

Fig. 3 The railway network plan for the YRD region (2020–2035). (NDRC 2020)

3.1 HSR and Competitive Mode Travel Time for Possible City Pairs

To investigate which travel mode could be more competitive in total travel time, we compare the travel time and distance between different city pairs in the YRD region. Of all 1640 city pairs, the city pairs with the top 25% GDP of origin and destination city were selected for further analysis since GDP was commonly found to yield a robust explanatory power in modelling and forecasting intercity travel demand [15]. We obtained the travel time and distance by retrieving the Gaode map API [16] for the fastest route. Various components of total travel time, such as access/egress, waiting, transfer if possible, and in-vehicle times were included based

Fig. 4 Travel time and distance comparison for different intercity travel modes for city pairs in the YRD region

on the route planned. Travel distance was measured by network distance between city administration centers. Using a map app to plan an intercity trip is common for intercity travellers. Therefore, the travel time obtained from the map has valuable meaning for intercity travellers. To ensure the data quality, we double-checked the obtained map API time based on travellers' revealed travel time between certain city pairs.

Figure 4 shows the relationship between travel time and distance for cars, HSR, and other public transit modes between city pairs. Intercity railway lines (marked as C trains in China) are categorized into the HSR type since the speed are more similar to the D train.

Results show that regarding total travel time based on the equation of HSR and car travel time and distance, HSR is hard to compete with car mode within 303 km. Despite the same travel distances, HSR travel time varies significantly between city pairs. This variance could result from the following reasons:

(1) the access/egress time in origin and destination cities. For example, from Huzhou-Shaoxing, with a travel distance of 135 km. The total travel time by public transport is 127 min with only 44 min for in-vehicle time. The high speed of HSR was weakened by the access time and egress time to HSR stations.
(2) short-distance city pairs without direct services. For instance, from Nantong to Zhenjiang, passengers have to interchange at the station of Changzhou or Nanjing.
(3) geographic location reasons, such as the city pair of Wuxi-Huzhou, divided by the Tai hu Lake, without straight routes available.

Expanding the HSR network to connect potential city pairs with direct links and better inter-intra-city connections between remote stations to central districts may improve the competitiveness of HSR and further facilitate the interaction between city pairs within the region.

3.2 Count of Cities for Return Trips Within a day

We further calculated the cities that could be accessed for a return trip based on a 3-h total travel time threshold of public transport (PT) modes. This threshold is selected based on the aforementioned articles indicating a 2–3 h travel time for a return trip to be completed within a day [1, 2].

In Fig. 5, the size of the ring represents a city that could access more cities or could be arrived at by more cities for a round-trip using public transport. Consistent with the result of the global efficiency analysis in Spain [4], node cities placed in the central position of the network achieve more accessible cities than the peripheral ones. The multi-direction connections link the central position cities, such as Nanjing, Hangzhou, and Bengbu, to more cities. We also observed that cities along the Shanghai-Nanjing corridor have access to more cities than cities along the Shanghai-Hangzhou corridor, thanks to the relatively shorter distances between cities along the Shanghai-Nanjing corridor. The situation of Jiaxing is also remarkable. Jiaxing is located between Shanghai and Hangzhou; however, the city could access fewer cities in a daily round trip due to the longer access/egress time from the administration center to the HSR station.

To identify the potential corridors for HSR promotion, we compared the travel time of public transport and car modes. Total travel time between the range of 3 and 4 h by public transport (PT), and with a longer travel time compared to cars are displayed in the left graph in Fig. 6. The high-volume corridor between the city pairs in the YRD region was identified in previous research [17]. Through the comparison between the two graphs, we could identify corridors of high intercity volume, but the HSR network and services are currently weak to compete with car mode for same-day return trips (marked by dash lines in the right graph). For example, Changzhou, Wuxi, and Suzhou show a high passenger volume to the city of Huzhou; however, the PT travel time for the three city pairs was 1.65, 1.96, and 1.93 times longer than car mode, respectively. The longer travel time by PT modes was caused by no direct services available between those city pairs. The connections between large cities and small-medium cities to large cities have been promoted by the HSR network. Our findings show the necessity to improve the efficiency of medium-to-medium city connections in detected corridors.

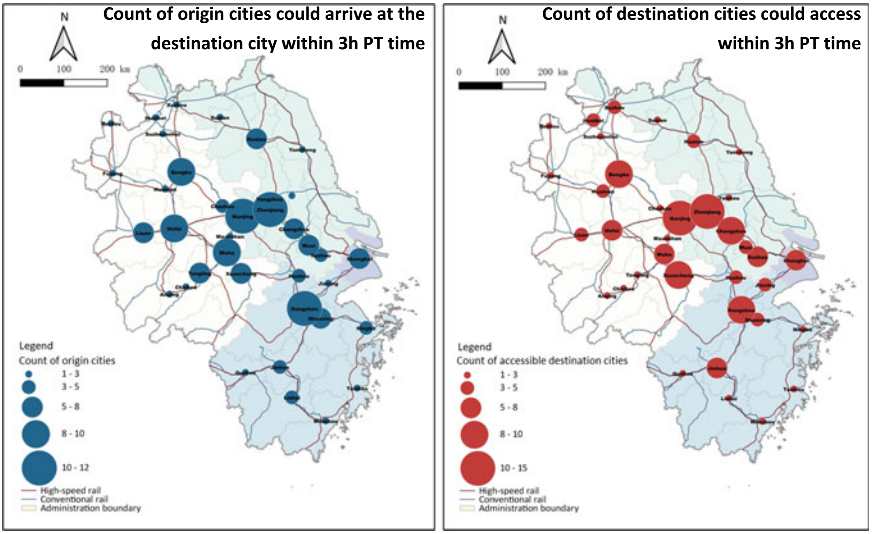

Fig. 5 Count of origin cities that could arrive at the destination city using public transport within 3 h (left) and count of destination cities that the origin city could access using public transport within 3 h (right)

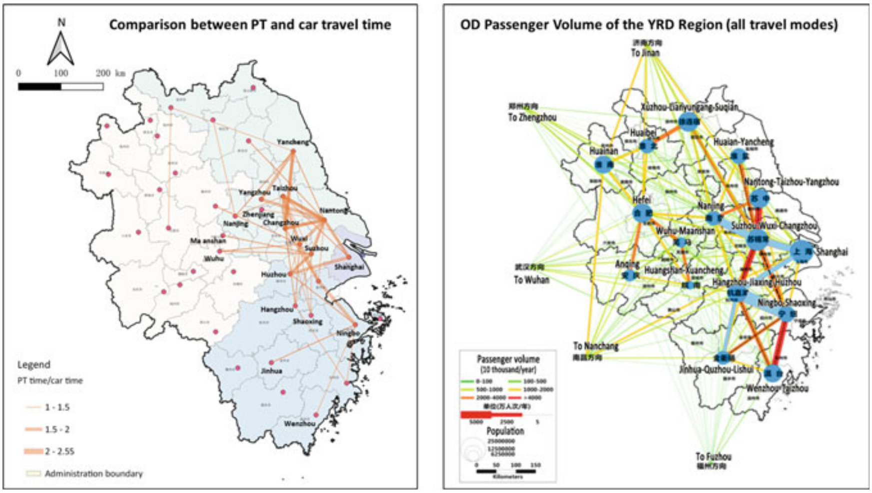

Fig. 6 Comparison between public transit time and car time (left), and OD passenger volume of the Yangtze River Delta Region (Zi 2021) (right)

4 Travel Behaviour and Spatial Distribution Characteristics of Intercity Travellers

Problems of using the traditional survey method for collecting intercity travel data have been discussed in previous research, which usually involves a high response burden, low number of respondents, and potential bias [18–20]. Two alternative data sources, GPS, and mobile phone data have been adopted in recent years [18]. Compared to GPS data, mobile phone data has the advantage of large sample sizes and easily obtain data at any period. This section explains how mobile phone data can be converted into individual trajectories, which are then used to identify intercity same-day return travellers' travel behaviours and to detect rail users.

4.1 Detect the Intercity Same-Day Return Travellers Using Mobile Phone Data

The mobile phone data used in our study was the cellular network-based positioning data from CHINA TELECOM. It is one of the three telecom companies in China, with a market penetration of 28.0% in Shanghai and 29.3% in Zhejiang province. The network-based positioning data utilize one or several base stations to locate a cell phone periodically, usually for 30 min. With the periodical positioning data, individual trajectories could be derived. The spatial resolution of the data varies from a few metres to several hundred metres based on the distribution of base stations [8]. Data resolution in the central area is usually more precise than in the peripheric area resulting from denser base stations inside the outer ring road of Shanghai (less than 1 km inside the outer ring road compared to around 3 km outside). The location estimation accuracy around the selected rail stations in Shanghai and Zhejiang provinces is generally around 150–500 m.

Data was collected between Feb 22 (a Monday) and July 11 (a Sunday) in 2021 for 20 full weeks. Since weekday trips involve more same-day return trips, trips within the 97 weekdays are kept for further analysis. By eliminating the holidays and weekends, the left same-day return trips are more likely to be business trips. We follow three steps to detect intercity travellers. Each stage of this procedure is detailed as follows:

First, an individual's home locations in Shanghai are detected. All night stay locations of a person between 11 p.m. and 5 a.m. (next day) on the 20 weeks are labelled, and the observed night stay location on each day can be counted. In our study, the count of night stay locations for most days and at least 60 days (based on three days per week for the 20 weeks) are labelled as home location.

Second, an individual's trip destinations for the same-day return trip are identified. The individual trajectories that depart from and end up with the home location (0–7 a.m. and 11 p.m. to the next day at 7 a.m. should be at the home location) and be observed in another city in Zhejiang province between 9 a.m. and 5 p.m. within a day.

Then the destination location in Zhejiang province, where a person being charged most inside a city from 9 a.m. to 5 p.m., was identified as the destination location for the individual's same-day return trip. Zhejiang province currently contains 11 cities, including Jiaxing, Huzhou, Hangzhou, Shaoxing, Ningbo, Wenzhou, Quzhou, Jinhua, Lishui, Taizhou, and Zhoushan. Due to the privacy issue in tracing an intercity traveller trajectory individually between subsidiaries of CHINA TELECOM (Shanghai and Zhejiang province are two subsidiaries), only charging reference in terms of call and internet usage records in another subsidiary is available.

Third, after home and destination stays are detected, the detected individuals are aggregated by origin Jiedao or destination city (Jiedao is the basic administrative unit of Chinese cities). For trip mode identification, speed-based methods, buffer zones around rail stations, or other machine learning methods have been applied to GPS data to detect travel modes [21]. In our study, if a person's trajectory passes by the selected railway station area, the individual is labelled as a rail user who used the station. We limit the railway station area to the block of the railway station instead of the buffer zone for higher accuracy. Examples of data collected are shown in Table 1.

In total, 34,567 individuals were detected from their homestay in Shanghai to a destination in Zhejiang Province for a same-day return trip within the 97 weekdays. After expanding the detected individuals to the whole population, the total number of intercity same-day travellers from Shanghai to Zhejiang Province was 1272 intercity travellers per weekday. We also detected 123,919 individuals from their homestay in Zhejiang to Shanghai for a round trip within a day. The total number of intercity same-day travellers from Zhejiang to Shanghai was 4360 individuals per weekday after expanding to the whole population in Zhejiang Province.

Table 1 Examples of data collected from home Jiedao in Shanghai to destination cities in Zhejiang Province

ID	Home stay	Destination city	Count of total trips within 97 weekdays	Detected rail user (1 = yes)	Rail station detected			Detected station for most days
					SHHQ	SHS	SH	
1	Jinze town	Hangzhou	9	0	0	0	0	NA
2	Xietu road	Hangzhou	8	1	0	1	0	SHS
3	Xinhong	Hangzhou	6	1	1	0	0	SHHQ
4	Beicai	Jiaxing	14	1	1	0	0	SHHQ
5	Changbaixincun	Jiaxing	5	0	0	0	0	NA

Note SHHQ-Shanghai Hongqiao Railway Station; SHS-Shanghai South Railway Station; SH-Shanghai Railway Station

4.2 Travel Behaviour and Spatial Distribution of Detected Intercity Same-Day Return Travellers

After detecting the intercity same-day return travellers using mobile phone data, we further explored the travel behaviour and spatial distribution characteristics of travellers.

Figure 7 shows the detected intercity same-day return travellers and the total number of trips stratified by destination cities in Zhejiang Province. In general, Hangzhou was the destination city for most one-day return travellers. Of the 34,567 individuals detected, 33,249 went to Hangzhou as the destination city. Both Hangzhou and Shanghai are core nodes in the regional structure. Our findings show that the same-day return travel demand between core cities was much stronger than between other nodes. Jiaxing, an intermediate city between Shanghai and Hangzhou, ranks as the secondary destination city receiving same-day return travellers from Shanghai. However, the intercity volume is far below Hangzhou. The difference in intercity flow may owe to the lower GDP, less population, and fewer attractions in Jiaxing.

The home stays of detected travellers from Shanghai are clustered in specific Jiedao units (Fig. 8). The adjacent subdistricts between Shanghai and Jiaxing, such as Zhujing and Fengjing Jiedao, showed more same-day return travellers. Also, more detected travellers were found from Jinshan and Fengxian new towns to Zhejiang province. Those subdistricts were connected to Zhejiang Province by highways (shown with brown lines in the bottom right graph). We also identified more same-day return travellers in spatial units near the three main railway stations, Shanghai South Railway Station, Shanghai Hongqiao Railway station and Shanghai Railway Station.

The detected travellers from Zhejiang Province to Shanghai show similar spatial distribution characteristics in Fig. 9, with more travellers distributed along the highway and railway corridors. The results indicate the effect of both highway and

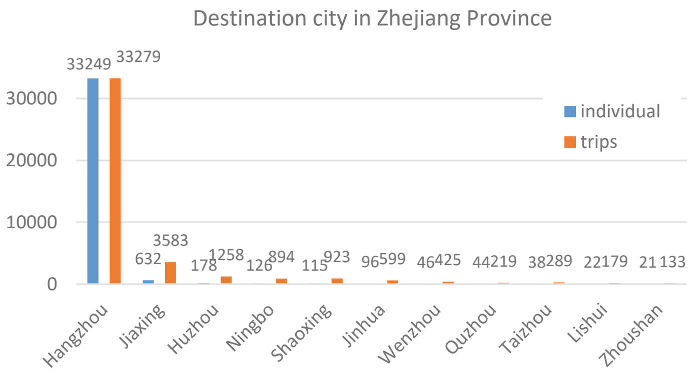

Fig. 7 Detected intercity same-day return travellers stratified by destination city in Zhejiang

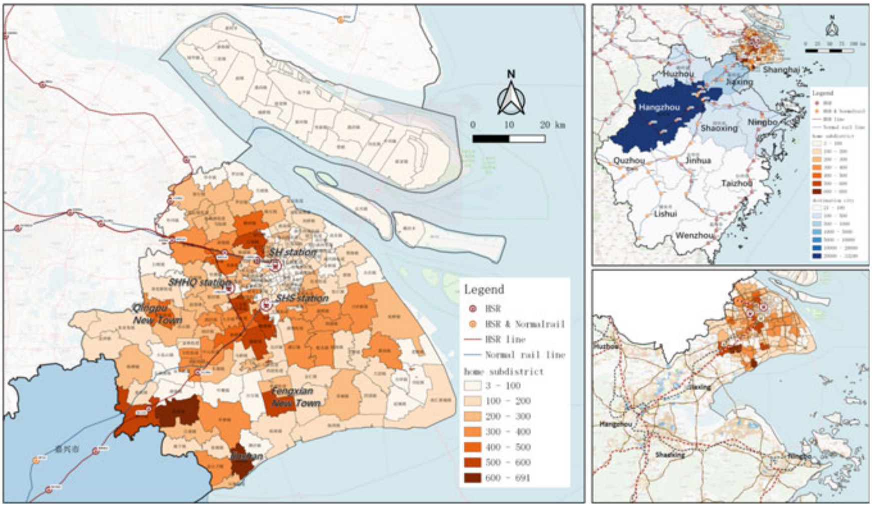

Fig. 8 Spatial distribution of detected traveller's to Zhejiang province aggregated by home Jiedao in Shanghai

rail networks in supporting the same-day return travel demand. The distance decay effects are noticeable along corridors, with most detected round-trip travellers to Shanghai within a 300 km radius. Subdistricts far from Shanghai than Tonglu, Yiwu, and Ningbo have fewer detected same-day return travellers. The total travel time using public transport modes from Shanghai to Tonglu, Yiwu, and Ningbo is between 3 to 3.5 h. Also, the in-vehicle time is about 1.5 h for the three OD pairs, which accounts for less than half of the total travel time. It highlights the need for promoting intra-city efficiency for round-trips within a day.

One advantage of mobile phone data is to capture intercity travellers' periodical travel behaviour. The detected individuals were grouped by their count of days to the destination cities in Zhejiang Province in Fig. 10. We found most travellers only travelled once from Shanghai to the destination city, and the majority of one-time travellers were to the destination city of Hangzhou. For groups that travelled to the destination cities for more than two days, more travellers arrived at the city of Jiaxing. The shorter distance between Shanghai and Jiaxing may lead to more frequent same-day intercity travellers. We also observed more same-day return reverse flow from Zhejiang province to Shanghai. Although Hangzhou is still dominant in the origin cities, we also detected same-day return travellers from other cities, such as Ningbo, Shaoxing and Wenzhou, to Shanghai in the one-time group. It implies an uneven in-and-out flow between Shanghai and other cities in Zhejiang province. However, the volume between Shanghai and Hangzhou is relatively balanced compared to the other city pairs.

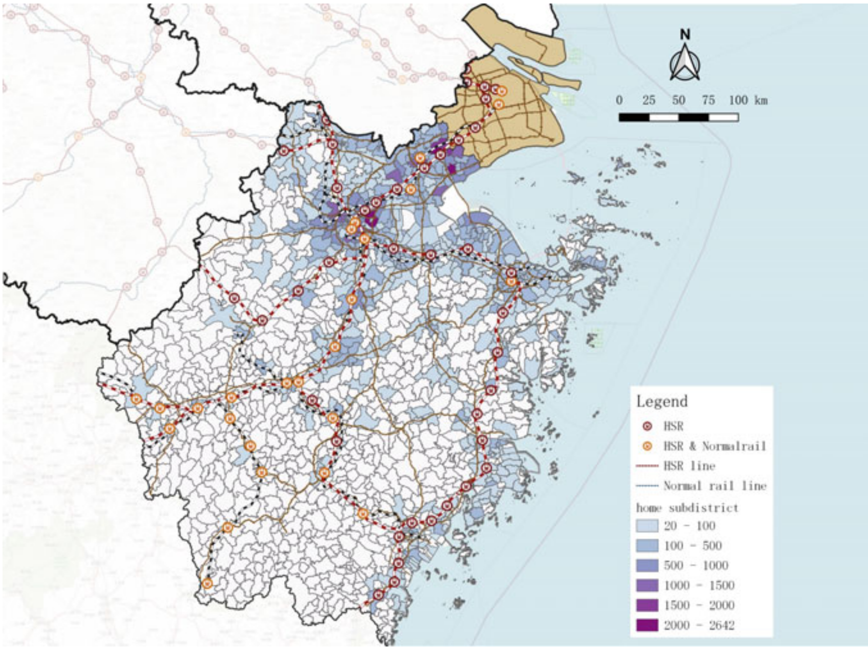

Fig. 9 Spatial distribution of detected traveller's to Shanghai aggregated by home Jiedao in Zhejiang Province

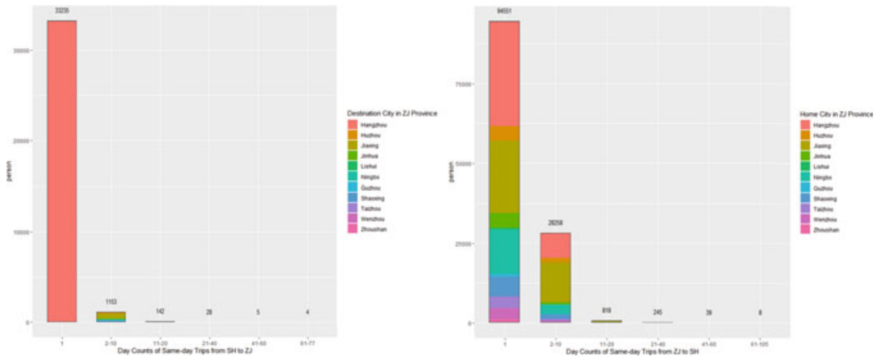

Fig. 10 Counts of detected same-day return travellers grouped by round trip days within the 97 weekdays

4.3 *The Explanatory Variables for Intercity Same-Day Travel Mobility*

The selection of the explanatory variables to model intercity same-day travel mobility is based on previous research and our interest. GDP, population, and distances

Table 2 Estimation results of intercity same-day travel mobility

	Estimate	Std. Error	t value	P value
β_0	−9.35438	3.81479	−2.452	0.0162*
β_1	−0.34092	0.10833	−3.147	0.0023***
β_2	0.859683	0.20951	4.103	0.0001***
β_3	0.005461	0.00243	2.247	0.0272*

Note *, **, and *** indicate statistical significance respectively at 10%, 5%, and 1% level. Adjusted R-squared is 0.64

between city pairs are commonly tested in previous gravity models for intercity mobility [22]. We added the attribute of rail service frequency, including D, G, and K trains. Although K trains are of the conventional rail system, they are included owing to more K trains from Shanghai South Railway Station to Hangzhou compared to the total number of G and D trains.

A gravity model was employed as it can provide effective estimation results and is widely used in previous intercity mobility analyses. The formula of same-day return travel mobility between the origin subdistrict Jiedao i and the destination city j is as follows:

$$SDR_{ij} = \exp\left(\beta_0 + \left(\beta_1 \ln\left(D_{ij}{}^2\right) + \beta_2 \ln\left(GDP_i * GDP_j\right) + \beta_3 SF_{ij}\right) + \varepsilon\right) \quad (1)$$

where D_{ij} stands for the distance and SF_{ij} represents the service frequency of G, D, and K trains in total. β_0 and ε are the intercept and error, respectively. Model results show that apart from *GDP* and distance, the number of trains to destination cities significantly positively affects same-day return travel mobility. Unlike previous research, which tested HSR service as a dummy variable of with and without HSR services [22], our result indicates that the service frequency should not be neglected in promoting same-day return travel mobility (Table 2).

5 Travel Behaviour and Spatial Distribution Characteristics of Rail Users

The detection of rail users is described in Sect. 4. After identifying the rail users, we analyzed the spatial distribution and catchment area of rail users of same-day return travellers.

5.1 Spatial Distribution of Detected Rail Users

To control the effect of detected numbers of rail users influenced by the different market penetration in Shanghai and Zhejiang, we compute the rail user percentage by dividing the detected rail users in Jiedao units by the total rail users identified in Shanghai and Zhejiang separately.

In Fig. 11, Jiedao units with darker colours represent a high proportion of rail users. We observed that spatial units of Jiedao near railway stations show a higher proportion of rail users. It is understandable since better accessibility in terms of distance to railway stations may positively affect rail users. Also, Jiedao units in big cities near Shanghai, such as Hangzhou Jiaxing and Ningbo, have a higher proportion of rail users. Those cities have higher GDPs and enjoy a shorter distance to Shanghai. However, the city of Huzhou is an exception due to low rail service frequency, as shown by the size of the yellow circle in the bottom left graph.

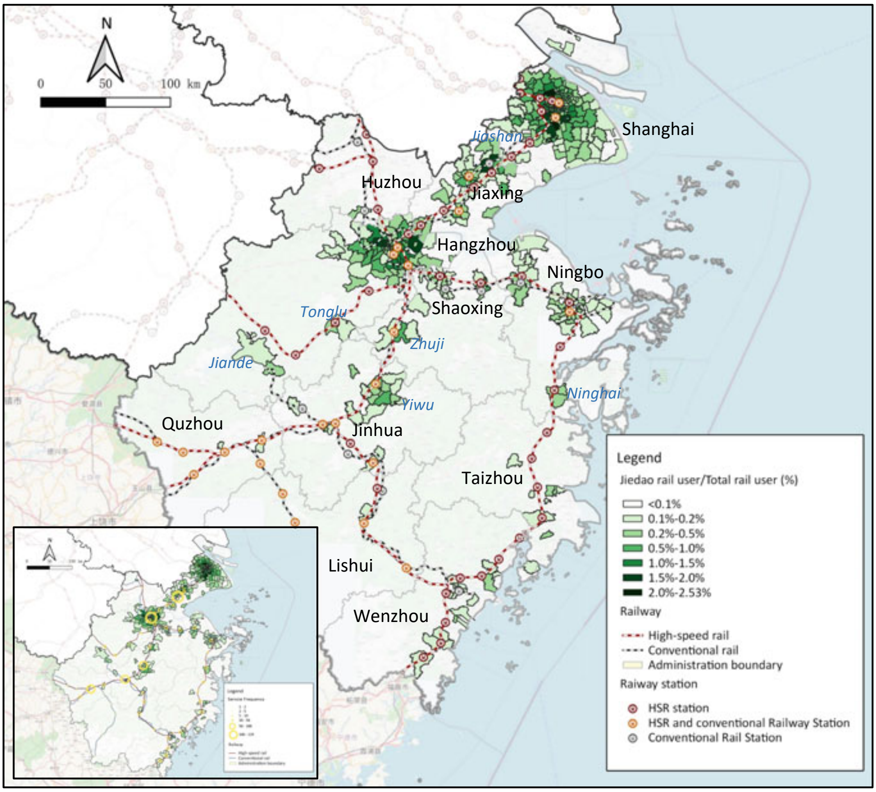

Fig. 11 Distribution of detected rail users in Shanghai and Zhejiang Province. (*Note* Shanghai rail user percentage calculated by detected rail user in Shanghai within a Jiedao divided by total detected Shanghai rail users; Zhejiang rail user percentage calculated by detected rail user in Zhejiang within a Jiedao divided by the sum of detected Zhejiang rail users)

Furthermore, we found relatively more rail users from the Quzhou–Jinhua–Yiwu–Hangzhou corridor to Shanghai than the Wenzhou–Taizhou–Ningbo–Hangzhou corridor or the Jiande–Tonglu–Hangzhou corridor. One possible explanation is that the Quzhou–Jinhua–Yiwu–Hangzhou corridor has a higher service frequency. There are 84 trains from Yiwu to Shanghai, compared to 47 trains from Ningbo to Shanghai and only 10 trains from Jiande to Shanghai per day (the number of services to the three main stations of Shanghai was summed up for efficiency calculation). High service frequency seems to trigger more rail passengers for same-day return trips.

Besides that, the catchment area based on home Jiedao was larger in mega-cities, for example, Shanghai and Hangzhou, than in medium and small cities. We infer that the subway system in mega-cities could induce the potential use of rail for same-day return trips.

5.2 Travel Time and Distances of Rail Users

Since the timestamp information in destination cities is unavailable for our data source, we retrieve the Gaode map [16] to obtain rail users' travel time and distance. Travel time and distances are calculated based on the detected rail users' homestays and their destination city's administrative centers. Due to the privacy issue mentioned in session 4, the administration center is treated as the destination place.

Figure 12 shows that of the detected rail users from Shanghai to Zhejiang Province, most travelled within 200 km, and more than 75% travelled less than three hours. It implies that the domain market share of the same-day return trip from Shanghai to Zhejiang by rail was within relatively shorter distances.

The comparison between the detected rail passengers using different railway stations and its relationship with distance decay explains different identified situations (Fig. 13). Shanghai Hongqiao (SHHQ) Railway Station has a higher HSR service frequency with a larger catchment area. Most detected travellers lived 25 km away from the station, leading to a longer access distance and time. The log-logistic decay function adopted by Martínez et al. [23] and the simple log form decay function were used to capture the distance decay for SHHQ and the other two railway stations. The fewer people living near Hongqiao Railway station could result from less residential land use in its closest hinterland and lower density nearby. Compared to the SHHQ railway station, the other two stations, Shanghai South (SHS) and Shanghai (SH) railway station, have lower HSR service frequencies. However, most detected travellers lived within 20 km network distances, and distance decay effects are apparent in these two stations. Unlike SH railway station, SHS station shows a higher number of detected rail users with more conventional trains. It indicates conventional rail could also be competitive with HSR for same-day return trips.

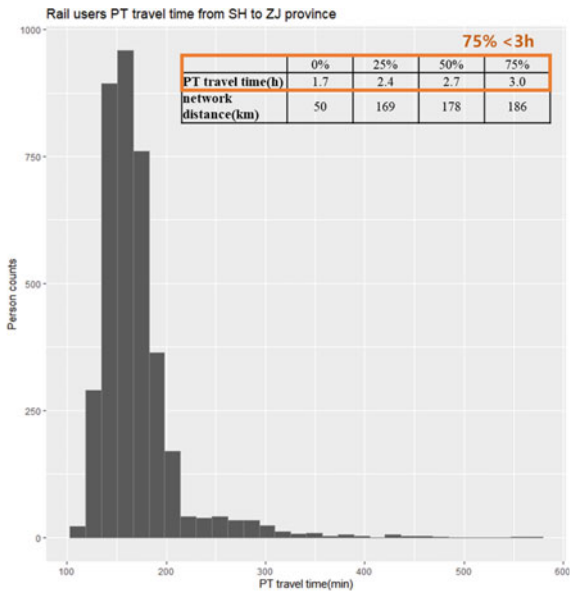

Fig. 12 Travel time and travel distances of detected rail users from Shanghai to Zhejiang Province

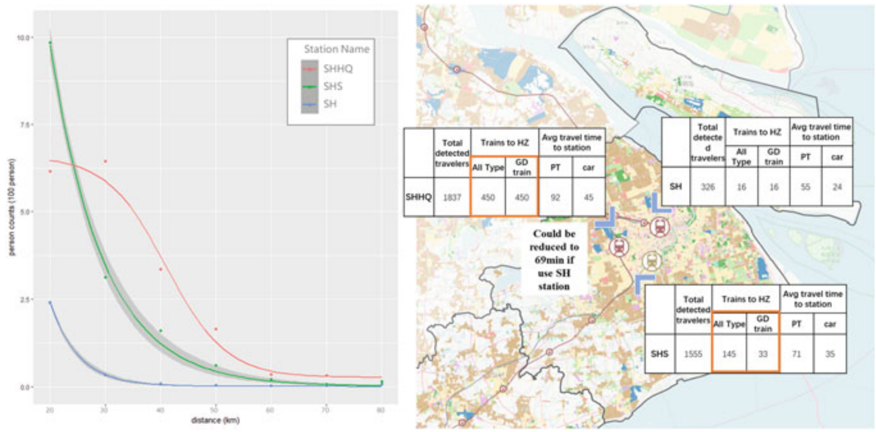

Fig. 13 Distance decay of three main railway stations in Shanghai. (*Note* The number of services to the different stations in Hangzhou was summed up for efficiency calculation)

6 Conclusion and Discussion

This study analyzes the same-day return travel between city pairs in the Yangtze River Delta Region and the efficiency of using High-speed Rail and other public transport modes for round trips within a day. From a demand side, we detected the same-day return trips between Shanghai and cities in Zhejiang Provinces using mobile phone data. The spatial distribution and periodical travel behaviour characteristics were identified with the 20-week data. The rail users were then detected by identifying individuals' trajectory paths passing through the railway stations. A comprehensive analysis of rail users for same-day return trips is expected to boost HSR and its efficiency, and further promote regional interaction and cohesion.

Travel time analysis of city pairs demonstrates that the efficiency of HSR is not as competitive as car mode within 300 km under the current network and services. Also, HSR efficiency varies significantly in different corridors. The supply of direct links, less transfer time and better inter-intra-city connections could be expected to enhance the same-day travel efficiency of HSR. Due to the geographic distribution of cities within a network, periphery cities could access fewer cities within a day than the central nodes. For periphery cities, shorter access/egress time is essential to improve the accessibility of those cities since most one-day return trips were within a 3-h travel time. The comparison between public transit and car mode travel time highlights the need for efficiency improvement to compete with car modes in high-volume corridors, such as Ningbo-Taizhou, Nantong-Suzhou, and Nantong-Changzhou.

The detected same-day return travellers using mobile phone data enable us to explore the spatial distribution and travel behavioural characteristics of intercity travellers, which are difficult to capture using traditional survey methods. We observed less demand for travel time longer than 3–3.5 h, and high service frequency corridors show more detected same-day return travellers. The gravity model results show that the GDP of the origin and destination city and rail service frequency is positively related to same-day return mobility. At the same time, the distance in between exerts a negative effect. Through the detected periodical travel behaviours of travellers, we found only a small amount of travellers from Shanghai to Zhejiang for high-frequency round trips. From Zhejiang to Shanghai, a relatively higher proportion of travellers travelled more than once within the 97 weekdays. The higher income level and better job opportunities in Shanghai may explain the difference. Also, the link between core cities Hangzhou and Shanghai shows a balanced in-and-out flow compared to core-periphery city pairs.

Detecting rail users allows us to investigate the travel behaviour of rail passengers and compare the catchment area of different railway stations. We found a higher percentage of detected rail users living near railway stations. Also, a higher proportion of rail users were found along corridors with high service frequencies from Zhejiang to Shanghai. For the catchment area of different railway stations, big cities show larger catchment areas than medium and small-sized cities for same-day return trips. The heterogeneity in distance decay for different railway stations was identified in Shanghai. The variance in distance decay may be due to the supply of land use near the railway stations and the number of train services to connecting cities. Reasonable conventional rail services can compete with HSR for same-day return trips.

Despite the above findings, there are certain limitations in our paper. Firstly, the data source is from one of the telecommuting companies in China with around 30% market penetration. Although the detected same-day return travellers were large enough to interpret their travel behaviour characteristics, future research using different data resources is needed. Also, for the detection of rail users, the probabilistic method, clustering method, and other advanced machine-learning models were adopted to identify the intercity travel patterns of people based on combined duration, speed, timetable, or route information [24, 25]. The data available only allows us to use the spatial analysis method to detect rail users, which may lead to fewer rail users being detected with irregular records of clients. Furthermore, the destination staying inside a city would be helpful in detecting the trip purpose of people. Future studies using high spatial resolutions for destination cities could potentially improve our understanding of the same-day return trip for different travel purposes.

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