Research on Pedestrian Accessibility in Large-Scale Railway Passenger Hub Areas

Lu Yuan[1)], Yang Xiaoze[2*)], Liu Meng[3)], Li Jingwei[4)]

[1)]School of Architecture and Design, Beijing Jiaotong University, Beijing, China, 100044, E-mail; luyuanup@foxmail.com
[2*)] School of Architecture and Design, Beijing Jiaotong University, Beijing, China, 100044, E-mail; zexyang@126.com
[3)] School of Architecture and Design, Beijing Jiaotong University, Beijing, China, 100044, E-mail; 616469357@qq.com
[4)] School of Architecture and Design, Beijing Jiaotong University, Beijing, China, 100044, E-mail; jwli3@bjtu.edu.cn

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Abstract

The concept of "integration of railway station and city" evolved from the TOD (Transit-Oriented Development) concept has become the future trend of the development of China's railway passenger transport hubs. Its core objective is to promote the transformation of the space within the hub station area from a "transit space" to a "destination space". Under this concept, the pedestrian system within the station area is regarded as the core link and key element connecting the hub station and the city. In this study, by constructing an accessibility evaluation model, combining data surveys and using the area ratio method, the walkability of 18 railway passenger transport hubs in four major urban agglomerations in China is evaluated, and the influencing factors causing the differences in their walkability are analyzed. The results show that there is a strong correlation between the walkability of the hub and factors such as the size of the hub, the density of the road network, express/elevated passenger drop-off lanes, pedestrian facilities, and internal transfer circulation lines. Among them, following the traffic-dominated spatial development model has become the main reason for the phenomenon of separation between the station and the city. Finally, the article puts forward measures and suggestions on how to improve the walkability of China's railway passenger transport hubs, and further strengthen the integrated development between the hubs and the city.

Keywords: *Large-scale railway passenger transport hub; Station area; Walkability; Transit-Oriented Development (TOD)*

1. Introduction

In China, rail transit infrastructure represented by high-speed railways has been rapidly constructed [1]. As of 2024, the total operating mileage of China's railways has exceeded 160,000 kilometers, among which the operating mileage of high-speed railways is over 46,000 kilometers, ranking first in the world. In terms of promoting the comprehensive development of the station area, China, combined with its own national conditions, has developed a brand-new concept of "integrated development of railway station and city" [2-3]. This concept emphasizes the deep integration of the transportation function of the hub and the urban function, and promotes the transformation of the space within the hub station area from a "transit space" to a "destination space". Among them, the pedestrian system within the station area is regarded as the core link and key element connecting the hub station and the city.

However, inconsistent with the emphasis on the pedestrian system in the concept, the pedestrian system within the station area of existing railway passenger transport hubs in China has not played its due role as a link (for example, in some representative hubs in China, the number of passengers walking in and out of the station accounts for less than 10% of the total scale). The fundamental reason is that a complete planning and design method and mode have not been formed. Different from the pedestrian system within the station area of conventional urban rail transit, the pedestrian system within the station area of railway passenger transport hubs shows characteristics such as complex transfer traffic organization (the walking process within the station building and inside the station cannot be ignored) and larger passenger flow scale. Although the relevant methods and theories summarized based on the research of urban rail transit pedestrian systems have certain reference significance [4-7, 10-11], they cannot fully meet the needs. Moreover, the existing few studies on the pedestrian system of railway passenger transport hubs also have problems such as a single sample size, limited research scope, and insufficient demonstration process [8-9].

Therefore, this study will take the pedestrian system within the station area of railway passenger transport hubs as the research object, use 18 representative hubs in China as research samples, adopt walkability as the research and evaluation method, analyze the promoting effect of the pedestrian system within the station area on the integration of the station and the city, and further analyze the influencing factors and action mechanisms. The implementation of this study not only fills the research gap in this field in China, but also serves as a window for the world to understand the comprehensive development experience of China's railway passenger transport hubs.

2. Research Design

2.1 Research Scope

The main object of this study is the area within the hub station that can be reached within a 15-minute walk, taking the railway passenger transport hub as the core and based on the TOD circular layer theory, with the entrance and exit of the hub station as the research starting point.

2.2 Research Objects

Taking into account the typicality, accessibility, diversity of the sample selection and the reliability of the evaluation results, this study selects a total of 18 large-scale railway passenger transport hubs within the four major urban agglomerations in China, namely the Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration, the Pearl River Delta urban agglomeration and the Chengdu-Chongqing urban agglomeration for research, as shown in Tab. 1.

Tab. 1. Research samples of 18 large-scale railroad passenger transportation hubs

Region	Hub
Beijing-Tianjin-Hebei	Beijing Station, Beijing North Station, Beijing West Station*, Beijing South Station, Tianjin West Station, Shijiazhuang Station
Yangtze River Delta	Shanghai Station, Shanghai South Station, Shanghai Hongqiao Station, Hangzhou Station*, Hangzhou East Station, Nanjing South Station, Hefei South Station
Pearl River Delta	Shenzhen North Station, Guangzhou South Station
Chengdu-Chongqing Area	Chengdu East Station, Chongqing North Station, Chongqing West Station

2.3 Evaluation Method

(1) Evaluation Indicators

Regarding the measurement of accessibility indicators, the spatial distance method is often used as a basic accessibility indicator in the study of the spatial pattern of the road network [10]. Scholars such as Ingram [12], Lisa [13], Handy [14], and Schlossberg [15] have chosen methods such as the distance ratio and area ratio to explore the accessibility related to spatial barriers in various regions.

In this study, the building of the railway passenger transport hub station is regarded as a whole for calculation. Since the walking directions of passengers arriving at and leaving the station are divergent, the form of a planar area is used to describe and evaluate the walkable accessible range. The interior of the hub is an important factor affecting the walkability within the station area, which also needs to be measured and evaluated. Taking the entrance and exit of the station as the demarcation point between the interior and exterior of the hub, the overall accessibility and internal influencing factors are evaluated and analyzed respectively. The evaluation method is shown in Tab. 2.

Tab.2. Data acquisition methods

Evaluation Aspects		Indicator Factors	Evaluation Method	Paraphrase	Note
Spatial walkability		The walkable accessible planar area	Area ratio method ($P = S_1/S_2$)	It is the ratio of the area that can be actually reached by walking for a certain period of time starting from a fixed point (S_1) to the area that can be reached by the straightline distance radiating from this point (S_2).	S_2, also known as the standard walkable accessible area, refers to the ideal accessible range assumed according to the walking speed of pedestrians. It is a circle drawn with the research base point as the center.
Analysis of Influencing Factors within the Hub	Factors related to hub characteristics	Station yard scale, station building scale, traffic volume scale, hub location, construction era	person	Based on statistical data, the Pearson correlation coefficient method is adopted to calculate the correlation between various influencing factors and pedestrian accessibility, so as to explore the influence degree of each kind of factor.	-
	Factors related to planning and construction	Total road network density; Density of high-speed and express road networks; Density of trunk road networks; Length of the rapid drop-off side; Density of branch road networks; Overpasses, underground passages or continuous three-dimensional pedestrian systems			-
	Factors of the Hub Itself	Pedestrian flow line	Direct distance measurement method (L)	Directly use the physical distance to measure the accessibility.	Compare the obtained results with the established hypothetical standard time.

The spatial scale of the actual walking reach (walking accessibility) was measured statistically using the following methods (Fig. 1 and 2):

$$A = \int_0^{15} L \quad (1)$$

$$\mathbf{L = V * Tt} \quad (2)$$

Eq:

L, walking reachable distance;

V, walking speed, about 5-6km/h (80-90m/min) for human;

Tt, walking time;

Eq:

T, the walking time outside the station house, the distance between the entrance and exit of the station and the destination, including horizontal and vertical movement time;

t, the walking time inside the station house which cannot be ignored, refers to the distance between the entry and exit gates to the entry and exit gates, including the horizontal and vertical movement time.

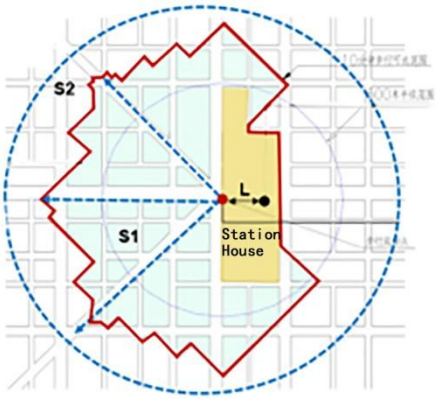


Fig. 1. Walking accessibility model for railroad passenger hubs

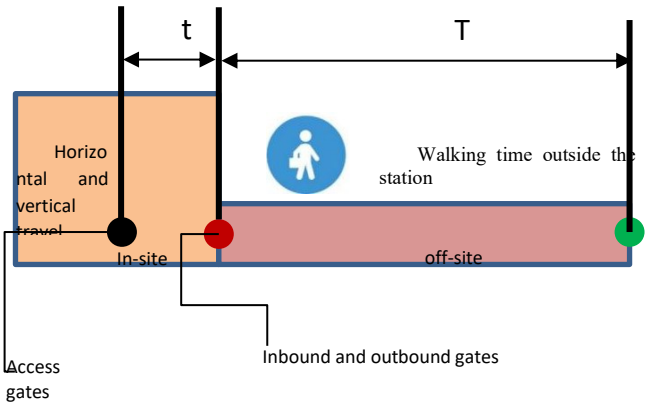


Fig. 2. Schematic diagram of the composition of walking time at a railroad passenger hub

（2）Time Scale

Base Point Selection: The selection of the base point location will, to a certain extent, affect the calculation of accessibility. Different from urban rail transit, large-scale railway passenger transport hubs have multiple spatial levels, different locations of entrances and exits, and complex entrance and exit flow lines. Therefore, in this study, the situations of entering and exiting the station are discussed separately. The entrances and exits on the ground floor that are accessible for passengers to walk are selected as the research base points.

Time Setting: In this study, 15 minutes is set as the total walking time, which includes two parts: the area outside the hub station building and the area inside the station building. Among them, the time inside the station building (t) is composed as follows:

$$t=t1+t2+t3+t4+t5 \quad (4)$$

Eq:

t1-the time required for the security check.

t2- time required for two real-name authentication before entering the station and boarding the train

t3-The sum of the two queuing times before entering the station and boarding the train;

t4-passing time for horizontal distance inside the station house;

t5-passing time of vertical distance inside the station house;

According to the actual investigation, the time required inside the station building is approximately 5 minutes. Correspondingly, the maximum time consumption (T) for passengers outside the station building when entering and exiting the station is 10 minutes.

（3）Data sources

This study relies on the data mostly for the basic attribute information of the hub and the actual walking flow statistical information, so the data acquisition method is mainly divided into two parts: network acquisition and field research, the data acquisition method is shown in Tab. 3.

Tab. 3. Data acquisition methods

Data source approach	Data categories	Data acquisition
Web Map Positioning and Measurement	Hub Station Location, Hub Station Passenger Standard Access Area, Reasonable walkable range of hub sites,Road network density	①Obtain the location of the hub station through Google Map;②Measure the standard accessible area of the hub station and the reasonable walking range of the station by using the Gaode Map measurement tool ;③Estimate the current land use data and road network density through Google Map and field research.
Acquisition of relevant information	Passenger hub site size information, station size information, traffic size information	Passenger hub sizes and flows are from the latest annual (2023) China Railway Statistics[16].
Acquisition of field research	The actual passenger access area of the hub station, the composition of the three-dimensional pedestrian system, Statistics on passenger entry and exit times,and the pedestrian flow of passengers inside the station.	①The actual passenger accessibility of the hub station area and the three-dimensional not work system composition for the experimental team field research combined with the Gaode map measurement tool calculations, calibration obtained;② passenger walking flow and entry and exit time for the Beijing West Railway Station in 2023, May 10-14, a total of five working days on-site research to obtain data statistics.

2.4 Modeling

Deeply exploring the influencing factors of pedestrian accessibility is the key to improving the level of pedestrian accessibility in the station area. According to the characteristics of the constituent elements of the pedestrian system in the hub station area, this study constructs a calculation model for its influencing factors:

$$A=f(Cn, Pn, In) \quad (4)$$

Eq:

Cn-(Characteristic) Hub Characteristic type of influencing factors（Tab.4）

Pn-(Planning) Influence factors of planning and construction category（Tab.5）

In-(Influence) Hub internal influences（Tab.6）

Hub characteristics, planning and construction and internal factors of the hub interact, superimpose and complement each other, and together determine the size of accessibility.

Tab.4 Methodology for analyzing factors affecting hub characteristics

Type of influencing factor	Indicators	Characterization data	Remarks
Characteristics	Station Size	Number of railroad yard platforms	The station data were published for the 2023 China Railway Statistical Yearbook [16].
	Station Scale	Building area of station buildings	
	Traffic Size	Annual passenger traffic of the station	
	Hub Location	Distance between station and city center	In the location problem, the people's government of each city is often located in the geometric center of the city, so it is used as the base point to start the study. Beijing and Chengdu are both square grid + ring layouts, so the geometric center point is chosen as the base point.
	Construction Year	Date of commissioning /expansion of station	Hubs that have undergone reconstruction and expansion are studied based on the time of their last major reconstruction.

Tab.5 Methodology for analyzing factors affecting planning and construction

Type of Influencing Factors	Indicators	Characterization indicators	Remark
Roadway Network Density	Motor vehicle-specific systems	Density of high and expressway network; rapid drop-off edge	The quantification of fast drop-off edge is only categorized into two cases, with (1) and without (0).
	Other road networks	Total road network density; arterial road network density; branch road network density	Only urban roads are counted in the road network area.
Continuous three-dimensional pedestrian system	-	Length of flyovers and underpasses	-

Tab. 6 Methodology for analyzing influencing factors within the hub

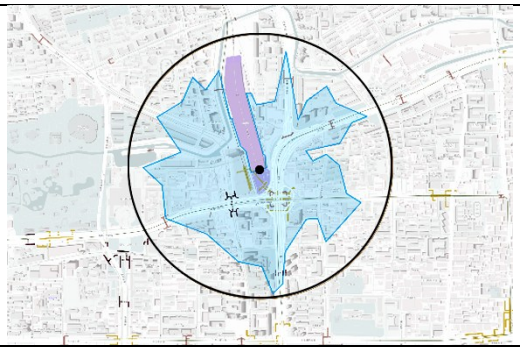
Impact Factor Category	Indicators	Characterization indicators	Statistical method
Passengers within the hub	Inbound time	Inbound horizontal walking time + vertical consumption time	Select a base point of entry and exit study on one side of the hub station, and count the average value of the distance between the nearest and farthest departure or arrival ticket gate as the horizontal distance of entry and exit, and for convenience of calculation, the horizontal walking time is obtained by dividing the horizontal distance by the stipulated step speed; combined with the research, the vertical passing time of each level in the station house is recorded as 1.5 minutes.
	Outbound time	Outbound horizontal walking time + vertical consumption time	

3. Descriptive statistics

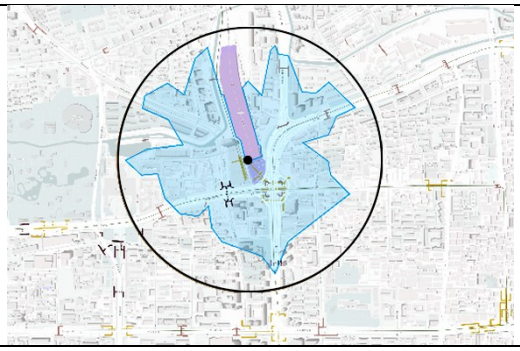
3.1 Analysis of Walking Reachable Area

In this study, the standard accessible area is drawn based on Baidu Maps, and the data of pedestrian isochrones are revised in combination with the situation of on-site investigations. Finally, the actual and theoretical accessible area data diagrams for a 10-minute walk in the hub station area are obtained. An example is shown in Tab.7.

Tab. 7 Schematic of the walkable perimeter of the hub station house



a-1. Beijing North Railway Station Inbound Study Base Points



a-2. Beijing North Station Outbound Study Base Points

b-1. Shanghai Station Inbound Study Base Point

b-2. Shanghai Station Outbound Study Base Points

3.2 Walking Accessibility Evaluation

The larger the actual-to-average ratio P obtained by the area ratio method, the better the spatial pedestrian accessibility around the station building.

As shown in Fig.4, there are obvious differences in the spatial pedestrian accessibility around the 18 railway passenger transport hubs.

(1) Beijing North Railway Station has the best spatial pedestrian accessibility, with a ratio of 0.465, which is much higher than that of the other 17 hubs.

(2) Those with relatively good spatial pedestrian accessibility are Hangzhou Railway Station, Beijing Railway Station, Chongqing North Railway Station and Shanghai South Railway Station, with ratios of 0.375, 0.34, 0.303 and 0.3 respectively.

(3) Those with average spatial pedestrian accessibility are Shanghai South Railway Station, Shenzhen North Railway Station and Beijing West Railway Station.

(4) Those with poor spatial pedestrian accessibility are Shijiazhuang Railway Station, Shanghai Hongqiao Railway Station, Hangzhou East Railway Station, Chongqing West Railway Station, Nanjing South Railway Station, Tianjin West Railway Station, Hefei South Railway Station, Beijing South Railway Station and Guangzhou South Railway Station. There are relatively large differences in the average pedestrian accessibility ratios on both sides of the station buildings of some stations, such as Beijing West Railway Station, Beijing South Railway Station, Tianjin West Railway Station, Shanghai Hongqiao Railway Station, Guangzhou South Railway Station and Chongqing North Railway Station.

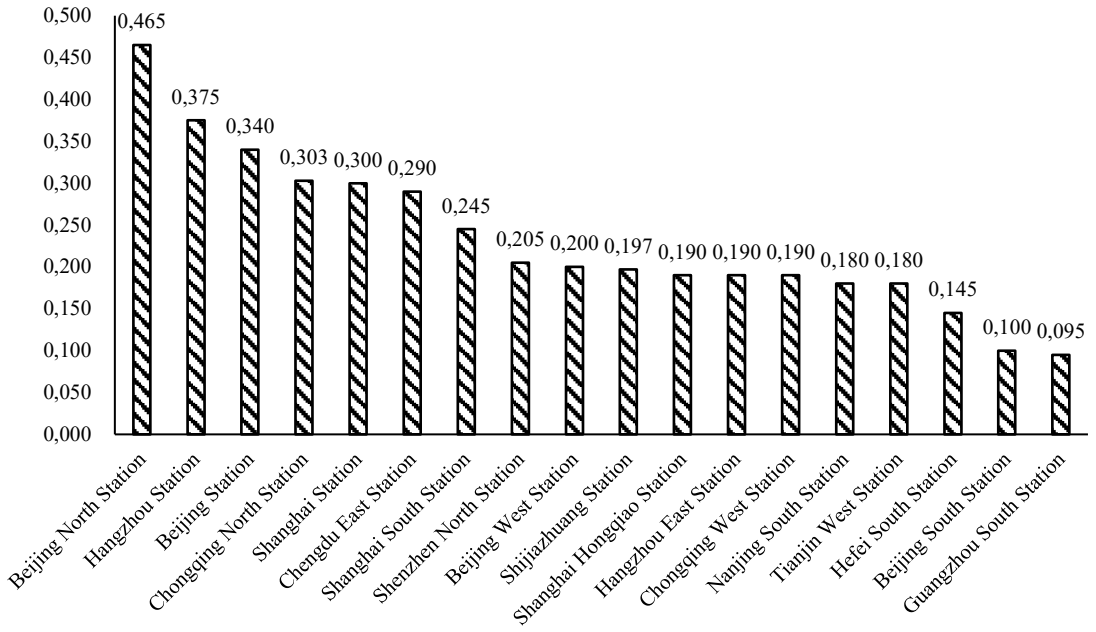


Fig. 4. Histogram of the mean value of the actual walkability ratio around the stations of 18 railroad hubs

4. Analysis of Influencing factors

4.1 Hub Characteristics Influencing Factors

The results of the correlation analysis show (Tab.7) that there is no correlation between the actual pedestrian accessibility ratio outside the station building and the traffic volume scale, while there is a significant negative correlation between it and the site scale, the station building scale, the station location and the construction era. That is to say, the size of the passenger flow scale does not affect the accessibility of the external space of the railway comprehensive hub. However, the larger the scale of the railway hub station or the station building, the greater the distance between the station and the urban central area, and the more recent the construction time of the hub, the worse the spatial pedestrian accessibility around the hub station.

Tab. 8. Correlation coefficients between the hub's characteristics and the mean value of the walkability ratio

Impact Factor Indicators	Indicator Factor	Indicator data	Pearson correlation coefficient	Significance (two-tailed)
Hub Characteristics	Station Size	X units	-0.553**	0.000
	Station Size	Building area (10,000 square meters)	-0.604**	0.000
	Traffic Size	Annual passenger traffic volume (10,000 passengers)	-0.156	0.259
	Station Location	Distance between station and city center (km)	-0.799**	0.000
	Age of construction	--	-0.433**	0.001

Note: **. Correlations are significant at the 0.01 level (two-tailed).

4.2 Influencing factors of planning and construction

The results of the correlation analysis show (Tab.9) that there is no obvious correlation between the actual pedestrian accessibility ratio outside the station building (hereinafter referred to as the ratio) and the density of high - speed and express road networks, but there is a significant negative correlation with the presence of express passenger - dropping sides. That is, the existence of express passenger - dropping sides will significantly reduce the external accessibility of the hub. The ratio has obvious correlations with the total road network density, the arterial road network density, and the branch road network density. Among them, the correlations with the total road network density and the branch road network density are higher. That is, the larger the overall road network density and the branch road network density, the larger the actual external accessible area. Since the branch road network density determines the degree of close connection between various spaces within the pedestrian area, it plays a key leading role in the convenience of the pedestrian network. The ratio has certain correlations with the lengths of overpasses and underground passages. That is, the longer the layout of the three - dimensional pedestrian network, the larger the actual external accessible area.

Tab. 9 Analysis of road network density and pedestrian accessibility

Impact Factor Category	Indicators	Characterization indicators	Pearson correlation coefficient	Significance (two-tailed)
Road network system	Motor vehicle-specific systems	Density of high and fast road network (km/km²)	-0.159	0.251
		Rapid drop-off side	-0.743**	0.000
	Other road networks	Total road network density (km/km²)	0.576**	0.000
		Arterial road network density (km/km²)	0.309*	0.023
		Branch road network density (km/km²)	0.570**	0.000
Continuous three-dimensional pedestrian system		Length of flyover (km)	0.324*	0.017
		Length of underpass (km)	0.363*	0.007

Note: *. Correlation is significant at the 0.05 level (two-tailed); **. Significant at the 0.01 level (two-tailed).

4.3 Factors affecting the interior of the hub

In the calculation of the accessibility within a 15-minute range, it was assumed in the previous text that the time required inside the station building (t) is 5 minutes, but the actual situation is not like that. Ignoring the internal management factors, the differences in the scale of the station building and the setting of the pedestrian flow lines lead to significant differences in the time taken to pass through the horizontal and vertical distances inside the station buildings of different stations.

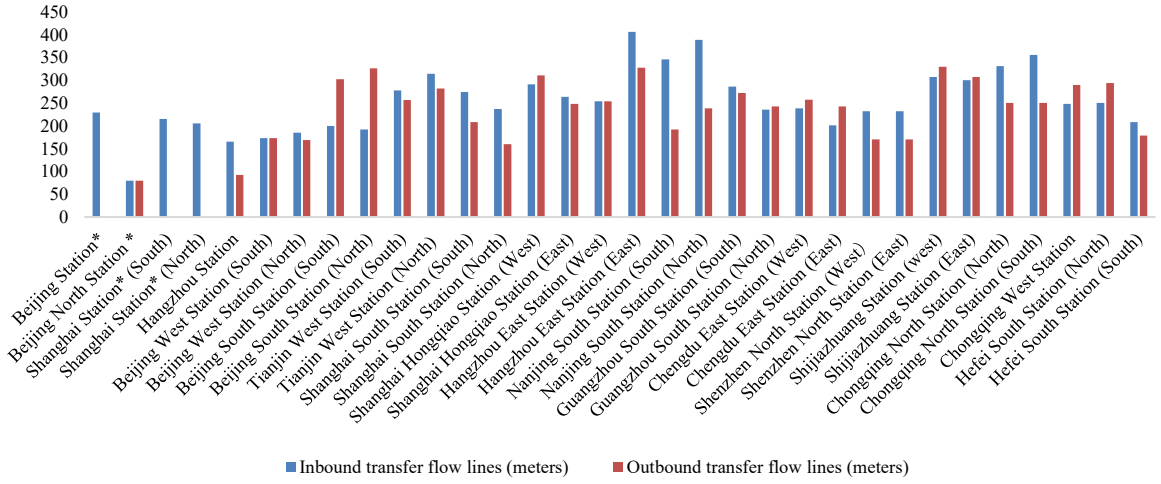


Fig. 5. Comparison of the length of passenger walk-in and walk-out transfer lines inside the station building

As shown in Fig.5: Except for Beijing North Railway Station, the walking time for passengers to enter the stations of each hub station is between 3 and 8 minutes, and the walking time for passengers to exit the stations is between 2 and 6 minutes. Variance statistics show that for railway stations other than Beijing Railway Station, Beijing North Railway Station, Shanghai Railway Station, Hangzhou Railway Station, Beijing West Railway Station, and Shenzhen North Railway Station, there are significant differences in the walking time for passengers to enter and exit the stations. The largest difference in the time for entering and exiting the station is at Nanjing South Railway Station (south side), with an entry time of 7.7 minutes and an exit time of 2.9 minutes.

For hub stations in the transportation complex mode, the average time spent by passengers walking into and out of the station buildings is between 3 and 6 minutes. Among them, the longest time spent is at Hangzhou East Railway Station (east side), which is 6 minutes; the shortest time spent is at Shenzhen North Railway Station (east and west sides), which is 3.2 minutes. Those with a time spent greater than 5 minutes include: Tianjin West Railway Station (north side), Shanghai Hongqiao Railway Station (west side), Hangzhou East Railway Station (east side), Nanjing South Railway Station (north side), Shijiazhuang Railway Station (west and east sides), Chongqing West Railway Station, and Hefei South Railway Station (north side), and the rest are between 3 and 5 minutes.

Regarding traditional stations where only the walking time for passengers to enter the station buildings of the hub stations is measured: The walking time for passengers to enter the station at Shanghai Railway Station (south and north sides) and Beijing Railway Station is between 4 and 5 minutes, and the walking time for passengers to enter the station at Beijing North Railway Station is 1 minute.

5. Conclusion

(1) Conclusion

Based on the evaluation of the walkability of railway passenger transport hubs and the analysis of influencing factors, the following conclusion can be drawn: The external spatial pedestrian accessibility of traditional stations is better than that of transportation complex hub station buildings.

Firstly, from the aspects of layout and main features: Traditional stations have a relatively small scale themselves. Relying on the original urban construction pattern of "small streets and dense road networks", the spatial pedestrian accessibility around the hub stations is relatively good. In contrast, transportation complex hubs emphasize efficient transfer and mainly adopt a three-dimensional

layout. The large space of the elevated overpass-style waiting halls leads to a relatively large building volume. While facilitating the entry and exit of traffic flows from all directions into and out of the hub, the design of the pedestrian system is neglected, resulting in a lack of close connection with the urban space and poor pedestrian accessibility. Thus, it can be seen that the characteristics and spatial organization concepts of the built comprehensive hubs are the main reasons for their poor spatial pedestrian accessibility.

Secondly, from the perspective of planning and design, the high-speed and express road networks around railway hub station buildings are often elevated or located underground, and their density has no correlation with the degree of pedestrian accessibility. However, the accessibility of railway hub station buildings has a strong correlation with the density of urban branch road networks. Traditional stations were built a long time ago and do not have express passenger-dropping sides. The existence of express passenger-dropping sides will have an obvious blocking effect on pedestrian movement in the station area.

Thirdly, through the analysis of the factors of the station building itself, it is found that the time consumed by passengers inside the station building far exceeds the expected 5 minutes. In transportation complex hubs, passengers spend 40%-60% of their time in the waiting area when entering the station. The "waiting-style" entry mode creates a large-scale waiting space, resulting in the entry distance being longer than the exit distance. This, in turn, causes differences in the time for entering and exiting the hub and becomes the main reason for the poor pedestrian spatial accessibility of transportation complex hubs. By calculating the walking time both inside and outside the station building together, it can be found that saving time inside the station can effectively increase the pedestrian accessible distance along the main road direction outside. The changes in the actual accessibility ratios of some hubs are shown in Fig.6.

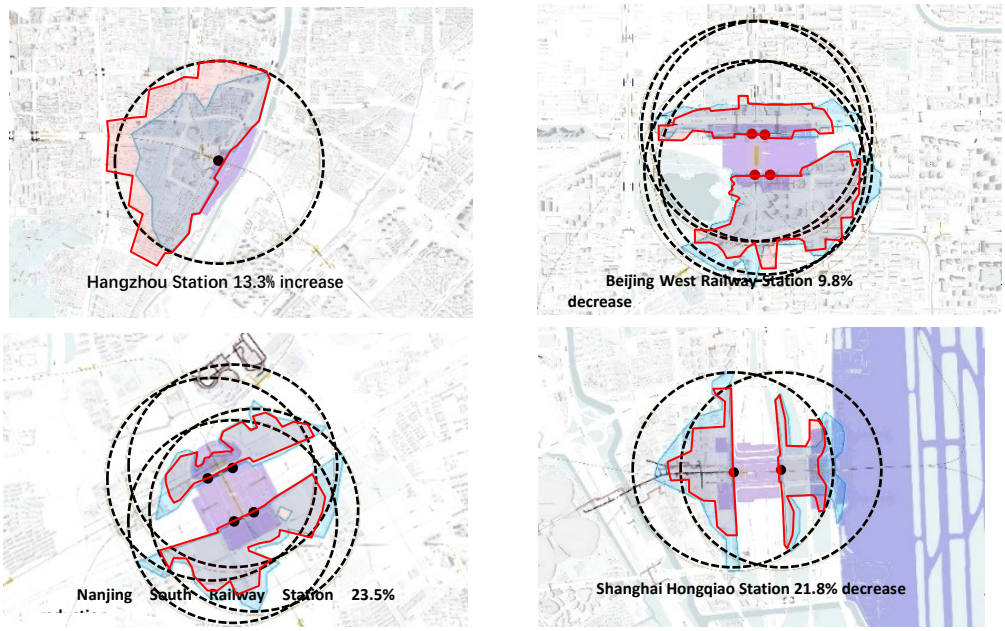


Fig.6 Changes in actual accessibility ratios of selected hubs under conditions of uniform consideration of internal and external walking time

(2) Optimization Strategies for Pedestrian Accessibility

From the perspective of the layout and design of hub construction, the huge single hub should be transformed into a layout of "regional node type - small and numerous". By renovating and adding new railway hub stations, the passenger flows from various directions can be dispersed. While reducing the scale of the waiting area, it can also reduce various management processes and time to a certain extent, and further improve the spatial utilization efficiency. At the same time, the land functions around the station building should be coordinated, and public service, commercial and other facilities should be configured with as high a density as possible. The large number of people brought by the railway hub should be utilized to promote the commercial operation of the upper cover area, and a core development node with both transportation and urban functions should be created, such as Beijing North Railway Station.

From the perspective of road planning and design, the density of branch road networks outside the hub should be increased, and a small-block and dense-road-network space suitable for walking should be created, so as to improve the efficiency of walking trips and enhance the convenience of connecting functional points. From the perspective of pedestrian friendliness, when designing the hub, an overall pedestrian network should be constructed to achieve a seamless connection with the urban public space and form an organic regional whole; continuous three-dimensional pedestrian facilities should be added at express road networks and intersections to enhance the pedestrian accessibility of this section of the road. Motor vehicles should be introduced underground through pipelines, realizing invisible traffic in the hub station area, and opening up the ground space to the urban space to the greatest extent.

From the perspective of internal management of the hub, the processes of entering and exiting the station should be simplified as much as possible, pedestrian instructions should be made clear, the situations of taking the wrong way and queuing up for a long time should be reduced, and the occurrence of uncertain situations inside the hub should be minimized.

(3) Research Limitations and Prospects:

Firstly, this study only explored the degree of accessibility from the objective spatial scale, but did not explore the accessibility of subjective psychology and resource control.

Secondly, currently, the hub is in the process of transformation from the transportation complex mode of integrated development of upper cover development and comprehensive utilization of the station yard to the urban complex mode. In the future, such a new development mode may enable us to obtain more effective resource accessibility within the limited accessibility.

In the existing discussions on the accessibility of large-scale railway hubs, the effective practice of not affecting the rapid arrival and departure system needs to be further explored in subsequent research.

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