Layout Patterns and Crowd Flows of Commercial Space in High-Speed-Rail Station Complexes

-- Take three Chinese high-speed-rail station complexes as examples

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Abstract

The commercial space in the high-speed railway station area is a key factor in stimulating the vitality of the crowd in the station area, and the station complex can maximally convert the transport value of the station area into comprehensive functional value. In the era of ordinary railways, the high-speed railway station was only regarded as a passenger transport hub. The commercial space was only used as a supporting facility to serve the transport interchange activities, which failed to attract the crowd to stay for long. Still, with the gradual increase in the proportion of short-distance and commuter passengers, however, as the proportion of short-distance and commuter passengers grows gradually, the commercial space in station complexes that have appeared in recent years has also failed to take into account the needs of both passengers and citizens. In this paper, based on the block layout relationship between commercial space, station access space, and urban transport space, we construct a "node-path" network of commercial space entrances and exits with high-speed rail station entrances and exits as well as urban traffic entrances and exits, analyse the correspondence between the commercial space layout pattern of the station complexes and the flow of crowds, and explore how different commercial space layout patterns influence the flow of crowds. It also discusses how different commercial space layout patterns affect the behavioural activities of the crowd. Finally, it concludes that: 1. Appropriately narrowing the distance between the commercial space and the station space of small and medium-sized passenger stations, especially placing underground space between the two, can stimulate the consumption potential of transport-oriented passengers who transfer to the underground. 2. The entrance and exit settings of the commercial space and the distribution of the flow of people are affected by the layout of the commercial space. 3. The commercial space entrances and exits related to the movement lines of underground passengers are also affected by the layout of commercial space blocks. 4. The entrances and exits of commercial spaces related to the moving lines usually have higher pedestrian flow. This study can provide new perspectives and methods for analysing the layout patterns of commercial space in station areas and offer design suggestions for improving the use of commercial space in station complexes.

Keywords

Station-city Integration; Station Complex; Commercial Space; Crowd Flow; Layout Design

1. Introduction

The high-speed railway station is an important transport intersection in the overall layout of the region, gathering a large amount of internal and external traffic in the city. However, the urban station hub area is not only a mobility node in the transport network but also an aggregation place in the city, and it is a waste of the value embedded in the circulation to use it only as a transport hub for the collection and distribution of human flow. Relying on the traffic advantage of the high-speed railway station to create urban functions such as commerce, business, exhibition, leisure, and so on in the surrounding area and organically integrating the traffic function (switching to articulation) with the urban function (commerce, office, leisure,

etc.) (Peng Qiyuan *et al.,* 2017), in addition, it can make full use of the transport value of high-speed rail stations, explore the urban place attributes of high-speed rail stations, and promote the linked development of high-speed rail stations and cities.

The commercial function is one of the main functions of utilising the overflow effect of station traffic effectively, and commercial space has rich spatial forms and types of business, that can meet the consumption needs of different groups of users. In China's high-density cities, where urbanisation is accelerating and land resources are relatively scarce, the joint development of station hubs and commercial facilities can realise the spatial connection between the two sides of the station and the city and promote the integrated development of the station and the city in the traffic hub area. For example, New York's Grand Central Station, London Bridge Station, and Tokyo's Shibuya Station have become important urban business and commercial centres.

As a comprehensive transport hub, the high-speed railway station in the high-density city centre has strong transport value and a functional development basis. It can closely connect with and interact with the neighbouring urban space, so it can rely on the transport advantage to enhance the comprehensive urban functional value of the station area, especially the commercial function that drives the area's economic growth. It is necessary to introduce commercial functions reasonably and appropriately, taking into account the needs of consumption activities of station passengers and neighbouring citizens, and to establish a close connection with other spatial elements in the station area to create a synergistic effect between the station and the city.

However, in the current practice of construction of commercial space in the high-speed railway station area, it is obvious that there is insufficient consideration of the user groups and their needs, especially since the resources of people flowing from both the station and the city are not fully utilised at the same time. In the era of ordinary railways, the commercial space of high-speed railway station complexes in China was mainly a supporting facility serving fast-passing passengers. With the gradual growth of the proportion of short-distance and commuter passengers, the user groups in the station area not only demand the station's internal and external traffic functions but also pursue higher-quality consumption and leisure functions. However, the commercial space of station complexes that have appeared in recent years, despite emphasising the integration of commercial space with the station and the city in terms of spatial form, still presents the result of mainly serving the use of part of the group, producing a large number of unused and inefficient commercial spaces. The practical exploration of creating station-city integrated commercial space is still in its infancy and lacks effective supporting theories and assessment methods.

The station complex mentioned in this study refers to a complex system that contains station space, urban transport space, and commercial space and has great potential to develop into a regional public centre. Compared with the single passenger transport function of a traditional station, a station complex contains more comprehensive urban functions that are closely linked to the station space, and the urban transport space is placed between the station space and the urban functional space, playing a transitional role in linking the station and the city, while the urban functional space crosses the red line of the station site and is laid out close to the station space (Fig. 1). Due to the high degree of integration of various functional spaces,

clear and convenient spatial organisation and flow guidance are required to ensure basic passenger distribution and transfer functions while avoiding mutual interference and influence between functional spaces.

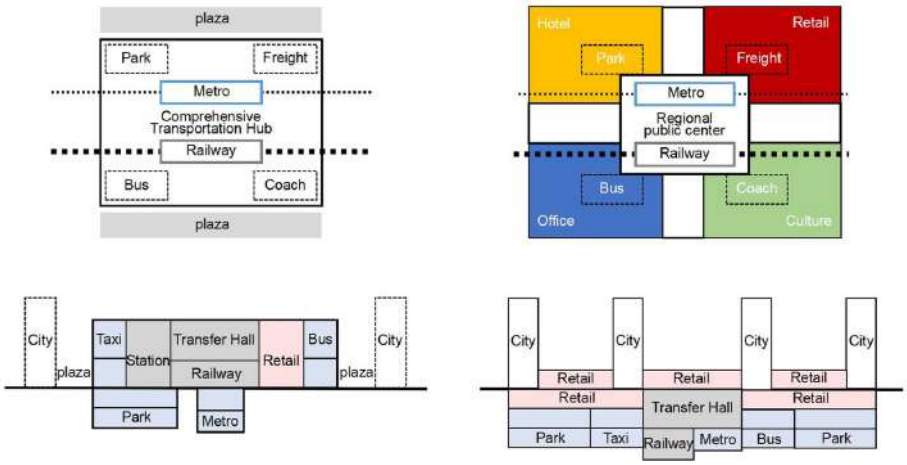


Fig. 1: Spatial pattern diagram of traditional stations and station complexes

Established studies have focused on the general organisation of station areas (Qi Guangping and LU Guanyu, 2019; Dai Yizheng *et al.*, 2018). Some studies have analysed the coupling relationship between commercial space and other spatial elements of traffic interchange activities (Gui Wangyang *et al.*, 2023; Yu Baofei and Ren Jun, 2021; Chen Binbin *et al.*, 2021). Few studies have focused on the fine-grained design of commercial space in high-speed rail station complexes from the perspective of passenger-citizen behavioural activity characteristics. On the one hand, existing studies have paid insufficient attention to the specific morphological design of commercial space in station complexes, lacked effective morphological analysis methods for commercial space layout, and have not yet answered the question of how the commercial space in station complexes should be linked to the station and the city, respectively. How should the commercial space of the station complex link the station and the city, respectively, and what role will other urban transport elements play? On the other hand, the existing studies have not deeply explored the influence of the layout of commercial space in station complexes on the flow of people, such as what kind of spatial use results will be brought about by different layout patterns.

This study selected Guangzhou East Railway Station, Chongqing Shapingba Railway Station, and Shenzhen North Railway Station, located in the centre of high-density cities in China, as the research samples. The commercial spaces of the three sample stations are similar in terms of industry composition but completely different in layout pattern. Among them, the layout pattern of the commercial space of the high-speed railway station complexes is broken down into two levels: block layout and node layout, and the crowd flow characteristics are mainly based on the data of pedestrian flow at the entrances and exits of the commercial space.

This study focuses on the layout of commercial space in high-speed railway station complexes. It builds a "node-path" network of commercial space entrances and exits with high-speed railway station entrances and exits and urban traffic entrances and exits based on the block layout. In addition, this study will classify the passengers and citizens in the commercial space of the station complex according to the purpose of travel and different types of urban transport, graphically present the behavioural activity chains of different groups, and explore the correlation between the behavioural activity characteristics of different groups in the station complex and the layout pattern of the commercial space.

The subsequent chapters are arranged as follows: Section 4 demonstrates the correspondence between the layout patterns of the commercial space of the sample station complexes and their crowd flow characteristics, Section 4.1 summarises the relationship between the commercial space of the sample stations and the block layout of the station space and urban transport spaces, corresponds the block layout characteristics of the commercial space of the sample station complexes to the total flow of people at all entrances and exits and analyses the impacts of different commercial space on the proportion of commercial space use. The impact of different commercial space layout patterns on the percentage of commercial space use is analysed. Section 4.2 abstracts the three types of functional blocks into multiple functional nodes, draws the behavioural activity chain of passengers and citizens going to the commercial space, respectively, constructs the relationship between commercial space entrances and exits with station entrances and exits as well as other urban traffic entrances and exits, corresponds the characteristics of the node layout of the commercial space of the sample station complexes with the flow of people at all entrances and exits, and analyses the effect of different node layouts of commercial space on the convergence of pedestrian flow at all entrances and exits. The influence of different commercial space node layout patterns on the gathering effect of pedestrian flow at each entrance and exit is analysed. Section 5 summarises the layout patterns of the commercial space of the sample station complexes, puts forward optimisation suggestions for different patterns, and proposes the commercial space layout suggestions of the high-speed rail station complex based on the characteristics of passenger-citizen behaviours and activities.

2. Literature Review

2.1 Study on the layout of commercial space in station areas

Theories related to functional space layout in station areas. TOD theory focuses on developing and constructing functional spaces that are closely linked to transport nodes. (Calthorpe Peter, 1993) Based on the study of high-speed railway station areas in Germany, France, Japan, and other countries, Schutz et al. were the first to put forward the circle structure model of the station area, i.e., with the increase of the distance from the station, the correlation between each functional space and the station gradually decreases and eventually forms a functional circle centred on the station. station-centred functional circles (Schütz Elmar, 1998). This theory initially explores the layout pattern of functional spaces in station areas. The commercial space of the station complex concerned in this study is located in the first circle,

which can take advantage of the traffic spillover effect of the railway station. The node-place model proposed by Bertolini is an analytical model for evaluating transport nodes from the perspective of public transport and land use based on the theory of the transport-land use feedback loop (Bertolini Luca, 1999; Bertolini Luca, 1996). The node-place model is an analytical model based on the theory of traffic-land use a feedback loop to evaluate transport nodes from the perspectives of public transport and land use (Bertolini Luca, 1996, 1999), in which the value of place is reflected in the development progress and development of the area around the high-speed railway station, and the use of commercial space is one of the indicators to measure the value of place in the station area, and the model can partly reflect the characteristics of the layout of the functional space and the effect of the use of station area.

Research and methodological tools for commercial space layout in station areas. Scholars have already classified commercial space in station areas into three categories: station commercial, station peripheral commercial, and peripheral area commercial, of which station commercial is commercial space developed integrally with station stations and transport facilities (Li Chuancheng *et al.*, 2016), which is consistent with the scope of commercial space that this study focuses on. Some scholars have also categorised commercial space as profitable building space and have analysed the coupling relationship between commercial space and elements of transport space and public space, proposing the layout patterns of tandem, adjacent, interspersed, composite, and cascading (Qi Guangping and LU Guanyu, 2019). In addition to conventional graphical analyses and qualitative descriptive methods, studies have been conducted to quantify the spatial organisation of station areas using urban spatial analysis tools such as Depth Map, such as exploring the correlation between the spatial integration degree of station peripheral areas and the functional layout of land (Du Qianyu and Zhang Fan, 2019). For example, to analyse the integration, connectivity, and comprehensibility of the underground interchange space of high-speed rail stations (Gui Wangyang et al., 2023), some studies abstract the complex urban spatial structure into graphical relationships based on urban morphology and building typology (Wang Zhendong & Wang Yindong, 2011). (Wang Zhendong and Wang Yinpu, 2015). The spatial structure of the station area is more complex, and it is difficult to determine a unified spatial reference point, but the connecting relationship between spaces can be expressed in diagrammatic form.

The distribution of crowd flow in the station area directly affects the use of commercial space. Still, few studies have analysed the connection between commercial space and other spatial elements in the station area from the perspective of crowd flow. Based on the above relevant theories, existing studies, and methods, this study will analyse the layout pattern of commercial space in station complexes from the two spatial floors of blocks and nodes by mapping the crowd flow in commercial space and summarising the layout pattern and expected usage effect of commercial space in station complexes.

2.2 Study on the crowd activity in station areas

Types of people who use the functional space in the station area. Studies have classified station users into two categories, namely "traffic transfer users" and "destination users" (Zhuo Weide *et al.*, 2022). For example, the destination segment is divided into four categories:

business, commuting, visiting relatives, and shopping (Wang Shaojian *et al.,* 2021). Other studies have analysed the functional space needs of different groups, such as short- and medium-distance passengers who are highly time-sensitive and have higher requirements for the accessibility of commercial space, long-distance passengers who are more likely to be price-sensitive and concerned about the type of commercial space, and citizens from the urban end of the city, who are more likely to have higher requirements for the quality and accessibility of commercial spaces (Wang Li, 2015).

Research and methodological tools for crowd activities in commercial space in station areas. Studies have used pedestrian simulation software to obtain complete data on crowd activities in station areas that cannot be collected in short-term studies, such as using AnyLogic software to simulate peak passenger flows in the distant future (Chen Binbin et al., 2021). For example, AnyLogic software is used to simulate the transfer situation of passengers leaving the station and to analyse the problems of the transfer space in the station based on the two indicators of transfer time and regional passenger density (Yu Baofei and Ren Jun, 2021). The problems of station transfer space are analysed based on two indicators: transfer time and regional passenger density. A large number of studies have also focused on the use of commercial office space in railway station areas, using field research, observation point counting, and other methods to obtain data such as the average number of people entering the shop per hour and the path flow of people to comprehensively evaluate the performance of the use of commercial space in the area of the railway station (Zhang Lingzhu *et al.,* 2019; Zhuang Yu and Yao Yiqian, 2016). This study mainly analyses the impact of the layout pattern of commercial space in station areas on crowd use, i.e., treating multi-floor commercial space blocks as a whole and ignoring the differences in the number of people entering the shop within the commercial space so that the use of the commercial space can be simplified to the flow of people converging to the entrances and exits of the commercial space.

Existing studies have mainly focused on transport interchange activities in station areas. Still, few studies have analysed the distribution among activities of different groups, or separately transport interchange activities and destination leisure activities, and the interweaving and transformation phenomenon of the dynamic lines of the two types of activities. In this study, according to the basis of traffic transfer and destination leisure groups and taking into account the different starting points of activities of tourists and citizens, the population using commercial space is classified into three categories: leisure citizens, traffic tourists, and leisure tourists, and the commercial space of the station complex is taken as the core to analyse the origin, flow, and process of the three categories of people converging to the entrances and exits of the commercial space in the station area.

3. Methods

3.1 Sample Selection

Since the urban location of the station affects the use of commercial space, this study selects high-speed rail stations located in the centre of high-density cities in China (Fig. 2) as samples among the station complexes that have been built and operated for many years and

have well-functioning commercial space: Guangzhou East Railway Station, Chongqing Shapingba Railway Station, and Shenzhen North Railway Station, which are located no more than 10km away from the city centre and represent different commercial space layout patterns of the station complexes. The scope of the study is the station access space, the multi-floor commercial space, and the urban transport space between them. Among them, urban traffic space which is far away from commercial space and does not have a spatial connection is not considered. The entrances and exits of the commercial space are set as the junction between the space of each floor and the external space. The vertical connection within the commercial space is not taken into account, i.e., multiple entrances and exits located at the same position in the commercial space of each floor are all connected with the external space of the ground floor through the vertical connection. Only the entrances and exits on the ground floor of the position are taken into account.

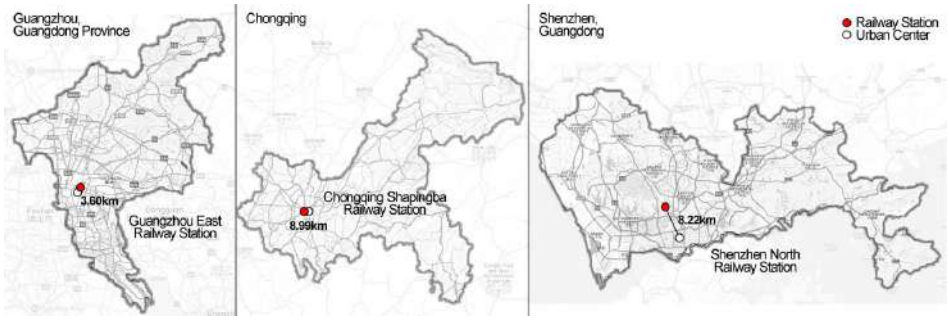


Fig. 2: Urban location of the sample stations

3.2 Layout analysis of commercial space in station complexes

First, the overall layout of the commercial space of the station complex is analysed. Through field research on the layout relationship between commercial space, station access space, and urban transport space, the "space-block" relationship of the three types of functional space is extracted. The second is to analyse the layout of the entrances and exits of the commercial space. Abstract the three types of functional spaces into corresponding functional nodes, take the entrances and exits of commercial space as the core, draw the footpaths of passengers and citizens who may pass by commercial space and whose destinations are commercial space, and construct a "node-path" network. In terms of the spatial object of the research, only the floors of commercial space that have a close spatial connection with the station entry and exit spaces are selected.

3.3 Pedestrian flow analysis of commercial space in station complex

The first is to compare the pedestrian flow in the station space and commercial space, and the proportion of the pedestrian flow in the commercial space to the total pedestrian flow in the station core area. The footfall in the station space is the total footfall entering and exiting the station; the footfall in the commercial space includes all the footfall passing through the

commercial space and the footfall destined for the commercial space; and the total footfall in the station core area is the footfall entering all the functional spaces. The second is to compare the pedestrian flow of each entrance and exit of the commercial space of the station complex. The research time is selected on weekdays, and taking into account that shops basically start the business at 10:00 a.m., the two time periods of lunch peak and evening peak are selected, and each time the people flow statistics lasts for 5 minutes.

4. Results

4.1 Layout and use of blocks of commercial space in station complexes

In the planning and design stage of a station complex, the number of passengers in the station influences the layout patterns of the functional space (Suo Chao and Zhang Hao, 2015). Considering the impact of the rapid in-and-out passenger flow of the station on the commercial space, the commercial space of the high-speed railway station complex will be appropriately far away from the in-and-out space of the station, and after the station complex is put into use, the location of the body layout of the commercial space usually significantly affects the overall use of the commercial space (Li Chuancheng et al., 2016).

4.1.1 "Space-block" layout of commercial space in station complexes

The commercial space of the station complex is usually chosen to face the external urban space, taking into account the accessibility of the public to the commercial space and the potential for passengers to pass through the commercial space on their way, including the urban transport space of the metro and motor vehicle loading and unloading points, which is usually laid out between the commercial space and the entrance and exit space of the railway station, i.e., forming a horizontal layout structure of external urban space, commercial space, urban traffic space, and station entrance and exit space. The passenger scale of Shenzhen North Station, Guangzhou East Station, and Chongqing Shapingba Railway Station decreases in turn, so the potential for integrating the commercial space of the station complex with the station space increases in turn. The average daily arrivals and departures of Shenzhen North Station are more than 0.2 million; the average daily arrivals and departures of Guangzhou East Station are about 0.05 million; and the average daily arrivals and departures of Chongqing Shapingba Railway Station are less than 0.01 million. The "space-block" layout characteristics of the commercial space of the three sampled station complexes are: far away from each other, overlapping, and overlapping, respectively (Fig. 3).

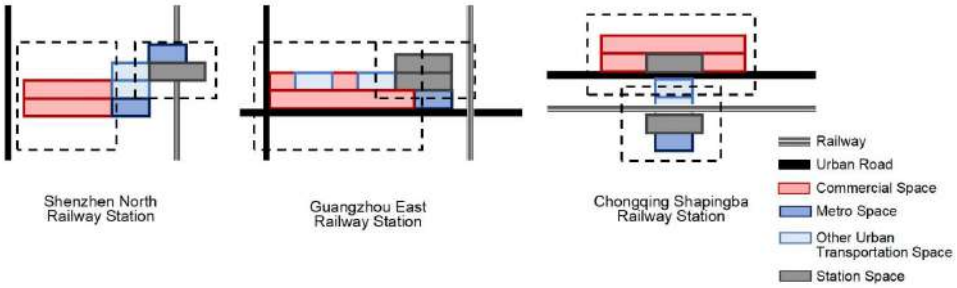


Fig. 3: Schematic layout of commercial space with station space and urban transport space

The commercial space of Shenzhen North Railway Station is completely separated from the station entrance and exit space, and between the two is an urban transport space integrating metro, buses, and taxis. The commercial space of this station complex consists of two floors with no vertical dislocation; the plan form is a U-shape facing south; and the concave space on the south side is a continuous outdoor promenade. The commercial space on the ground floor is connected to the metro station hall, and the commercial space on the second floor is connected to the transfer hall for buses and taxis. The city-facing area of the commercial space is adjacent to only one city road, with city roads farther away in the other two directions (Fig. 4). The shop formats are mainly catering, retail, and lifestyle services.

The commercial space of Guangzhou East Railway Station is intertwined with the station access space, and the urban transport space is embedded between the two. The commercial space of this station complex has four floors, and this study only considers the ground floor and the first underground floor, which are closely connected with the station space and the urban transport space. These two layers of commercial space are in the shape of a ladder; the ground-floor commercial space is located on the south side of the station space; between the two is the motor vehicle lane and drop-off area; the ground-floor commercial space is deep below the station space; and the underground station hall is below the station space. The city-facing area of the commercial space is adjacent to three city streets with plenty of pavements and overpasses (Fig. 4). The shop formats are mainly catering, retail, and life service, with the ground floor mainly for fast food, the first basement floor mainly for retail business, supplemented by a small number of catering businesses, and life service businesses and hypermarkets located in the second and third basement spaces.

The commercial space of Chongqing Shapingba Railway Station is completely superimposed with the station access space and urban transport space, and all kinds of urban transport space are spaced out from the station access space, and the commercial space is located above the two, adjacent to the station access space. The main part of the commercial space of this sample station complex is five floors, and the local part is seven floors, only the ground floor and the first floor, which are closely connected with the station space and urban transport space, are considered in this study. These two floors of commercial space are located entirely on the ground, and the plan form is a dumbbell shape distributed on both sides of the

station building, and the east and west sides are connected through the aerial connecting corridor that spans above the station space with the commercial space on the ground floor. The commercial space is close to several urban roads and overpasses (Fig. 4). The shop formats are equally dominated by catering, retail, and lifestyle services.

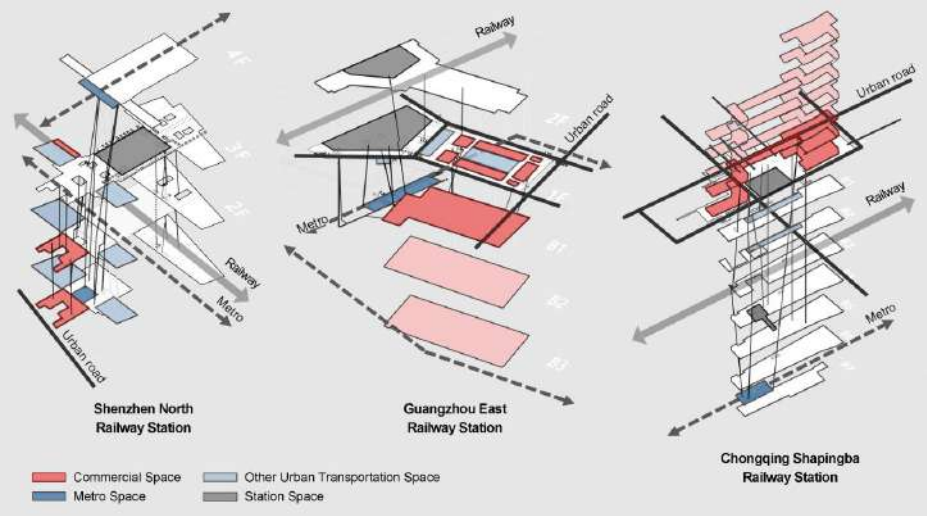


Fig. 4: General layout of commercial space in the sample station complexes

4.1.2 Total footfall of commercial space in station complexes

The pedestrian flow in the station space is usually proportional to the size of the station passenger flow, while the pedestrian flow in the commercial space is jointly influenced by the size of the passengers and the layout location of the commercial space. Based on the passenger scale of the station, the influence of the layout location of the commercial space of the station complex on the flow of people is analysed by comparing the relative size of the commercial space flow of the sample station to the station space flow of people and the proportion of the commercial space flow of people to the total flow of people.

As shown in Fig. 5, the percentage of commercial space use in Guangzhou East Station, Chongqing Shapingba Railway Station, and Shenzhen North Railway Station decreases in turn. Guangzhou East Station has a higher commercial space footfall than its station space; Chongqing Shapingba Railway Station and Shenzhen North Railway Station both have a lower commercial space footfall than station space footfall; and Chongqing Shapingba Railway Station has a relatively small gap between commercial space footfall and station space footfall. Among them, Guangzhou East Station, which has a medium passenger size, has the highest pedestrian flow of commercial space in its staggered layout, while Chongqing Shapingba Railway Station, which has a smaller passenger size, does not have a pedestrian flow of commercial space in its overlapping layout that exceeds that of Guangzhou East Station. In addition, although the pedestrian flow in the commercial space of Chongqing Shapingba Railway Station is lower than that of Shenzhen North Railway Station, the total pedestrian flow

of the former is much smaller than that of the latter, and thus the commercial space usage ratio of Chongqing Shapingba Railway Station is still higher than that of Shenzhen North Railway Station, which also shows that the calculation of the respective commercial space usage ratios of the sample stations can be used to make effective comparisons between the stations.

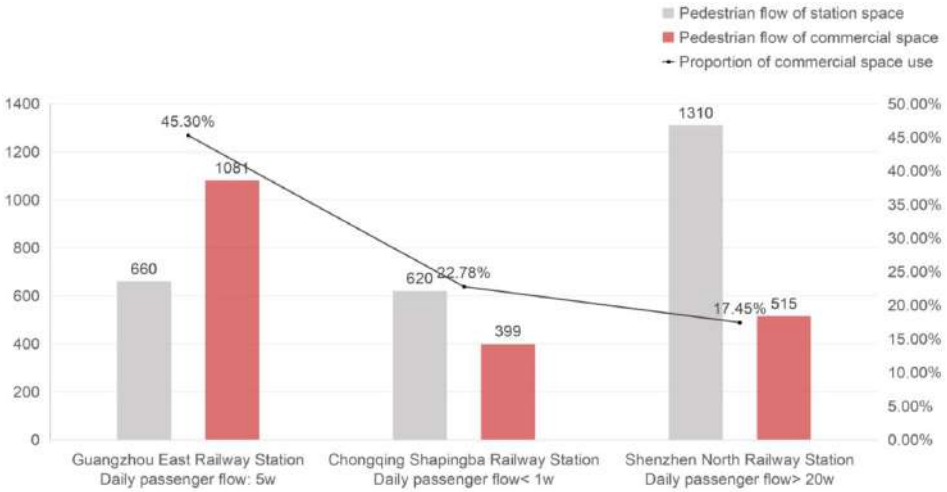


Fig. 5: Total footfall in commercial space of the sample station complexes

4.2 Nodal layout and use of commercial space in station complexes

In addition to the above commercial space block layout, the actual use of commercial space in station complexes is also affected by the more microscopic layout of entrances and exits. The node layout relationship between the commercial space of the station complex and the station entrance and exit space and urban transport space affects the origin, flow, and convergence of people travelling to and passing through the commercial space, and the "node-path" layout is reflected in the flow of people through the various entrance and exit nodes of the commercial space.

4.2.1 "Node-path" layout of commercial space in station complexes

The main users of commercial space in the station complex are leisure citizens (citizens who specially go to and use commercial space within the radius of the station), traffic passengers (passengers who pass through the commercial space in the process of entering and exiting the station by railway), and leisure passengers (passengers arriving by railway and especially go to and use commercial space), and the urban transport means to be chosen are underground, taxi, bus, and so on. The starting point of the passenger's movement is the station entrance and exit node, while the starting point of the citizen's movement is the various urban transport nodes, which are usually located between the commercial space entrance and exit

node and the station entrance and exit node. The movement of the two groups will cross and overlap, and there are commercial space entrances and exits shared by both the passengers and the citizens.

As shown in Table 1-3, the entrances and exits of the commercial space of Guangzhou East Station are mainly distributed at the end near the station, and only two ground-floor entrances and exits are set up in the city-facing area; the 16 entrances and exits of the commercial space of Chongqing Shapingba Railway Station are located at the ground floor and above; the entrances and exits of the commercial space of Shenzhen North Railway Station are set up both at the near-station end and the near-city end, of which eight entrances and exits are set up in the near-city area, and six entrances and exits are set up in the near-station area. The "node-path" layout of the commercial space of the three sample station complexes takes into account both passengers and citizens and has the potential to attract transport and leisure passengers in addition to serving as leisure shopping destinations for citizens in the vicinity.

The commercial space at Guangzhou East Railway Station can attract transport-oriented passengers transferring to the metro, and most of the entrances and exits of the commercial space are exclusively for passengers or citizens. Passengers who choose to transfer to the metro and citizens who take the metro to the commercial space are distributed in the same area, but the two movements do not interfere with each other. Passengers transferring to the metro will pass through Entrance 6/7/9 in the process, while citizens arriving by metro will enter the commercial space through Entrance 5 or Entrance 7, and Entrance 7 will be shared. People choosing buses, taxis, and walking will enter the commercial space through Entrance 2, Entrance 1/8, and Entrance 1/2/3/4/8, respectively. Leisure passengers travelling exclusively to the commercial space will mainly enter through Entrance 1/6/9. Entrance 1 will be shared by taxi-only citizens and leisure passengers, so Entrance 2/3/4/8 will be the exclusive entrance for citizens entering the commercial space, and Entrance 6 and Entrance 9 will be the exclusive entrance for passengers entering the commercial space.

The commercial space at Chongqing Shapingba Railway Station is not able to attract transport-oriented passengers entering and leaving the station, and its commercial space entrances and exits are only partially shared. People who choose the metro to go to the commercial space enter through Entrance 1/2/6/7, those who choose buses and taxis enter through Entrance 1/2, those who choose private cars enter through Entrance 4/5/12, those who choose to walk can enter through Entrance 1/2/3/6/7/8/9/10/11/12, and leisure passengers who go to the commercial space exclusively enter through Entrance 1/2/4/5, i.e. Entrance 6/7, which is directly accessible from the metro station hall on the seventh floor of the underground, and Entrance 6/7, which is directly accessible from the metro station hall on the seventh floor of the underground, as well as Entrance 6/7, which is directly accessible from the metro station hall on the seventh floor of the underground. Entrance 6/7, which is directly accessible from the MTR station hall on the seventh basement floor, and Entrance 3/6/7/8/9/10/11/12, which is accessible on foot from the city road, are the entrances and exits of the commercial space for public use.

The commercial space of Shenzhen North Railway Station attracts transport passengers entering and leaving the station on foot and the public walking to the commercial space, and their entrances and exits to the commercial space are shared by both passengers and the public.

Traffic passengers who choose to enter the station on foot and citizens who walk to the commercial space enter through Entrance 1/2/8/9/10/11/12/13/14 facing the city, while traffic passengers who choose to leave the station on foot, leisure passengers who go to the commercial space exclusively, and citizens who choose the metro, buses, and taxis enter through Entrance 3/4/5/6/7/12/13/14 adjacent to the station. There are no entrances or exits to commercial space exclusively for the public.

Table 1: Node-Path Layout of Commercial Space in Guangzhou East Railway Station

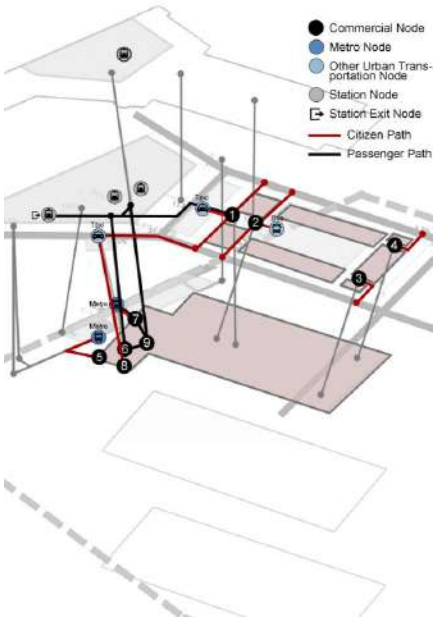
	Traffic Passengers (through commercial space)	Entering the station by metro	Metro --- E7 --- E9 --- E6 --- Entrances
			Metro --- E7 --- E9 --- Station
		Exiting the station by metro	Station --- E6 --- E9 --- E7 --- Metro
			Station --- E9 --- E7 --- Metro
	Leisure Passengers (to commercial space)	Station --- E1 / E6 / E9	
	Leisure Citizens (to commercial space)	By metro	E5 / E7
		By bus	E2
		By taxi	E1 / E8
		On foot	E1 / E2 / E3 / E4 / E8

Table 2: Node-Path Layout of Commercial Space in Chongqing Shapingba Railway Station

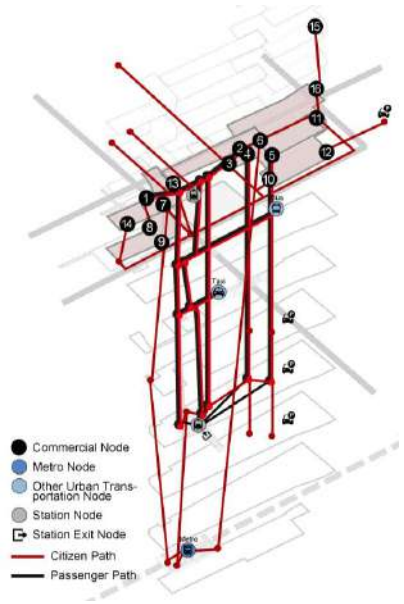
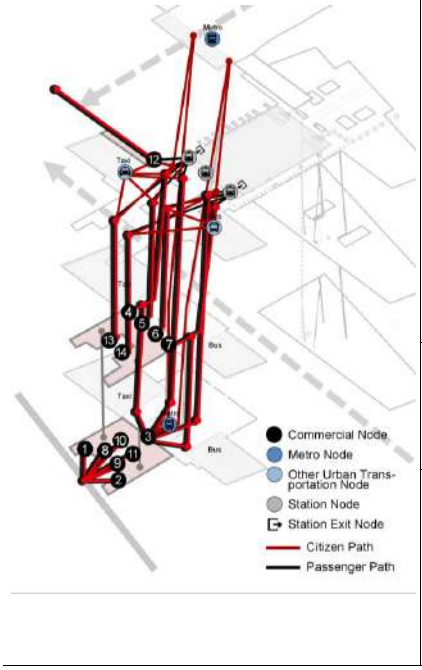
	Leisure Passengers (to commercial space)	Station --- E1 / E2 / E4 / E5	
	Leisure Citizens (to commercial space)	By metro	E1 / E2 / E6 / E7
		By bus	E1 / E2
		By taxi	E1 / E2
		By private car	E4 / E5 / E12
		On foot	E1 / E2 / E3 / E6 / E7 / E8 / E9 / E10 / E11 / E12 / E13 / E14 / E15 / E16

Table 3: Node-Path Layout of Commercial Space in Shenzhen North Railway Station

	Traffic Passengers (through commercial space)	Entering the station on foot	Urban road --- E1 / E2 / E8 / E9 / E10 / E11 / E12 / E13 / E14 --- E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14 --- Station
		Exiting the station on foot	Station --- E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14 --- E1 / E2 / E8 / E9 / E10 / E11 / E12 / E13 / E14 --- Urban road
	Leisure Passengers (to commercial space)	Station --- E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14	
	Leisure Citizens (to commercial space)	By metro	E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14
		By bus	E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14

		By taxi	E3 / E4 / E5 / E6 / E7 / E12 / E13 / E14
		On foot	E1 / E2 / E8 / E9 / E10 / E11 / E12 / E13 / E14

4.2.2 Pedestrian flow at entrances and exits of commercial space in station complexes

The pedestrian flow at the entrances and exits of commercial space in station complexes reflects the convergence effect of the "node-path" chain with different attributes. By comparing the average flow of people at the entrances and exits of the commercial space in the sample station and the flow of people at each entrance and exit, we analyse the influence of the node layout of the commercial space in the station complex on the flow of people.

As shown in Fig. 6-8, the number of entrances and exits in the commercial space of Guangzhou East Railway Station is the lowest, but the flow of people at each entrance and exit is more than 50, and there are two entrances and exits with higher than average flow of people, and the difference between the highest flow of people and the lowest flow of people reaches 164 people. Chongqing Shapingba Railway Station has six entrances and exits with higher-than-average passenger flow, and the difference in passenger flow between them is relatively small. Shenzhen North Railway Station has four entrances and exits with higher than average passenger flow, and the difference in passenger flow between the entrances and exits is in the middle.

Among the entrances and exits in the commercial space of Guangzhou East Railway Station, the ones with higher than average flow rates are Entrance 7 and Entrance 9 on the basement floor. Entrance 7 is common, and the flow rate is much higher than the other entrances and exits. It is directly opposite to the main axis of the commercial space on the basement floor, and it is the necessary entrance and exit for the traffic passengers who are transferring to the metro and for the leisure passengers who are taking the metro (Fig. 9). Entrance 9 is a special entrance for the passengers and is connected to the ground floor through the staircase facility. Entrance 9 is one of the entrances for passengers, connected to the ground floor through the staircase facility, and is close to the station access space on the ground floor, which can be used by leisure passengers and transport passengers transferring to the metro.

Among the entrances and exits of the commercial space of Chongqing Shapingba Railway Station, the ones with higher than average pedestrian flow are Entrance 1, Entrance 2, Entrance 4, Entrance 6, Entrance 7, and Entrance 11 on the ground floor. Entrance 1, Entrance 2, and Entrance 4 are shared entrances and exits, which are accessed by leisure citizens who choose to take the underground, bus, taxi, and walk, as well as by leisure passengers who travel to the commercial space exclusively (Fig. 10), and Entrance 4 is connected by a straight staircase to the station exit space and private car garage at the fourth basement floor, which is shared by leisure passengers and those who choose to travel by private car. Entrance 4 connects the station exit space on the fourth basement floor and the private car garage on the ground floor via a

straight staircase, which is shared by leisure passengers and leisure citizens who choose to travel by private car. Entrance 6, Entrance 7, and Entrance 11 are dedicated entrances for citizens, with Entrance 7 mainly carrying leisure citizens travelling on the underground, and Entrance 11 being one of the entrances for citizens to walk into the commercial space.

Among the entrances and exits of the commercial space of Shenzhen North Railway Station, the ones with higher than average pedestrian flow are Entrance 1, Entrance 3, Entrances 4+7, and Entrance 12, which are across the three floors of the commercial space. Both passengers and citizens share these five entrances and exits. Entrance 12 is close to the station space and leads to the commercial street adjacent to the station's entrance and exit space, which has the highest flow of people and is one of the shared entrances and exits for all passengers and citizens (Fig. 11). Entrance 1 is close to the city road and mainly accommodates transport passengers entering the station on foot and citizens walking to the commercial space. On the other hand, Entrance 3 and Entrances 4+7 are located in the area close to the station space and are used by transport-oriented passengers who choose to walk out of the station, leisure-oriented passengers who travel exclusively to the commercial space, as well as citizens choosing the metro, buses, and taxis.

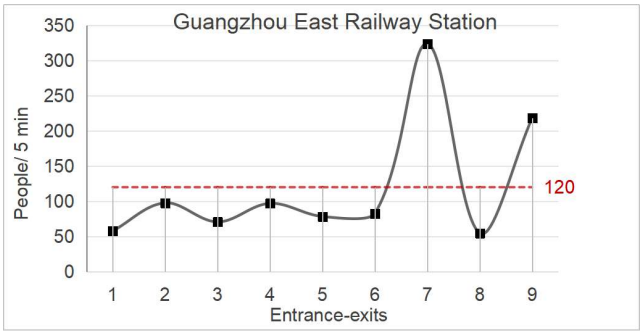


Fig. 6: Nodal pedestrian flow in commercial space of Guangzhou East Railway Station

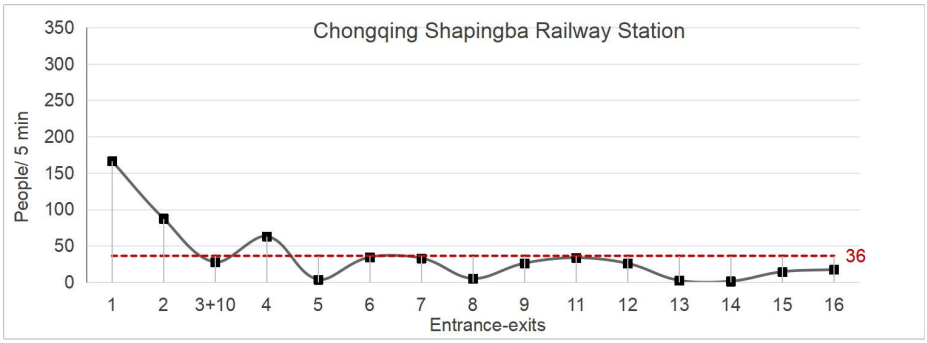


Fig. 7: Nodal pedestrian flow in commercial space of Chongqing Shapingba Railway Station

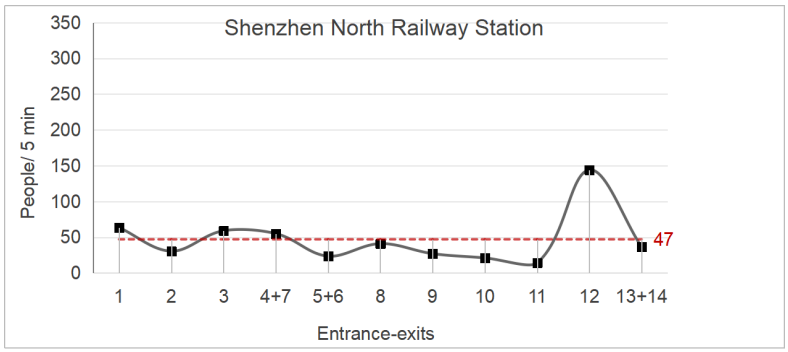


Fig. 8: Nodal pedestrian flow in commercial space of Shenzhen North Railway Station

Fig. 9: Pedestrian flow at E7 of Guangzhou East Railway Station

Fig. 10: Pedestrian flow at E1 of Chongqing Shapingba Railway Station

Fig. 11: Pedestrian flow at E12 of Shenzhen North Railway Station

5. Conclusions

The circle structure of centre agglomeration is usually regarded as an ideal model for the high-density development of high-speed railway station areas, while this study is based on the walking line of two types of groups, tourists and citizens, to refine the deduction of the design of the layout form of the commercial space of the high-speed railway station complex, which includes two aspects, namely, the layout of the body of the commercial space and the layout of the nodes at the entrances and exits.

Firstly, the correlation law between the block layout of the commercial space of the station complex and the total pedestrian flow. There is no positive correlation between the distance of commercial space from the station space and the use of commercial space, and the commercial space with the closest and the farthest distance from the station space shows a lower percentage of commercial space traffic, while the commercial space with the station space in a staggered layout and with the distance between the two in the middle of the commercial space, on the contrary, has a higher percentage of commercial space traffic. The reason is that the interlocking commercial space and station spaces have strong spatial connections, and the metro space is embedded between them, which attracts a large number of transport-oriented passengers to pass through the commercial space.

The proportion of long-distance passengers in the core area of China's high-speed railway stations is very large, and passengers' demand for rapid transportation is much larger than their demand for leisure consumption; therefore, the people who use the commercial space of station complexes are mainly leisure-oriented citizens in the surrounding area, and the number of leisure-oriented citizens > the number of transport-oriented passengers > the number of leisure-oriented passengers. Therefore, in the process of planning and laying out the commercial space of station complexes, attention can be paid to stations with small and medium-sized passenger scales, appropriately shorten the distance between their commercial space and station entrance and exit space, and create a staggered space for guiding traffic passengers, especially by placing

underground space between the two and stimulating the recreational potential of traffic passengers who transfer to the underground, whereas, in stations with large-scale passengers, the distance between their commercial space and station entrance and exit space needs to be maintained to provide a more comfortable and comfortable environment for the passengers. For stations with a large passenger scale, the commercial space and the station access space need to be kept at a distance for the use of the neighbouring citizens and a small number of passengers.

Second, the node layout of the commercial space of the station complex and the correlation law of the entrance and exit pedestrian flow. Firstly, the setting of entrances and exits of commercial space and the distribution of people flow are influenced by the layout of commercial space blocks. Located in the commercial space on the side of the station space, its entrances and exits are distributed in the area close to the station and facing the city, and there is a big gap between the flow of each entrance and exit. Located in the commercial space directly above the station space, its entrances and exits are distributed on the ground floor where the two are intersected, and because these entrances and exits are facing the surrounding city, the gap between the flow of each entrance and exit is relatively small. Secondly, the entrances and exits of the commercial space that are connected to the metro line usually have high pedestrian flow. Among them, the passenger-citizen shared entrances and exclusively for public use entrances and exits with a direct spatial connection with the underground line have a higher flow of people, while the entrances and exits exclusively for leisure passengers have a higher flow of people close to the station entrances and exits. Therefore, in the process of planning and laying out the commercial space nodes of the station complex, it is necessary to enhance the spatial connection between the entrances and exits of the commercial space, the metro space, and the station entry/exit space based on the block layout form of the commercial space.

Then, the layout pattern and optimisation suggestions for commercial space in the sample station complexes are:

Guangzhou East Station and Shapingba Railway Station are stations with small and medium-sized passenger scales. The commercial space of Guangzhou East Station is interlaced with the station space, with metro space embedded between the two, and the entrances and exits of the commercial space are separated for the exclusive use of passengers or citizens, especially the special entrances and exits set up for the transport-oriented passengers who change to the metro, so that the commercial space of this station complex can attract a large number of transport-oriented passengers changing to the metro while accepting citizens from the surrounding areas. The passenger scale of Shapingba Railway Station is relatively small, and its commercial space is completely superimposed with the station space, between the two there are urban transport spaces such as buses, rentals, and private garages, while the underground is located below the station exit space, and most of the entrances and exits of the commercial space are shared by citizens and passengers, and only a small number of entrances and exits are for the exclusive use of the citizens who take the underground and go to the commercial space on foot, and the commercial space of this station complex mainly serves the peripheral citizens, and only accepts a small number of leisure-type passengers. citizens, and only takes on a small number of leisure-type passengers. However, Shapingba Railway Station does not attract traffic passengers who must pass through the commercial space, and the passenger flow of the station is mainly concentrated in the ground floor entrances and exits, and the flow of people inside the

commercial space lacks traffic power, so it is possible to increase the commercial space and adjust the position of the entrances and exits of the commercial space between the station exit space and the underground to accept the traffic passengers who transfer to the underground.

Shenzhen North Railway Station is a station with a large passenger capacity. Its commercial space is completely separated from the station space, and between the two, urban transport spaces such as metro, bus, taxi, and private garage are integrated in a three-dimensional way, with entrances and exits to the commercial space shared by passengers and citizens, and a separate commercial street is set up in the area adjacent to the entrance and exit of the station, which is supplemented by the use of leisure-type passengers. Citizens choosing either mode of transport share all entrances and exits to the commercial space with leisure passengers who visit the commercial space exclusively and transport passengers who enter and exit the station on foot. Due to the large area of interchange space and station square between the station space and the surrounding urban roads, the number of transport passengers walking in and out of the station is minimal. The commercial space is far away from the station space. Even if it is close to the entrances and exits of the station space, the accessibility is low, so leisure passengers will choose to go to the commercial street, which is close to the entrance and exit of the station. The citizens who go on foot will also go to the commercial street, so the area gathers a large number of passengers and citizens. Therefore, the area gathers a large number of passengers and citizens. However, the distance between this commercial street and the two-floor commercial blocks is relatively far, so the vertical connection between the two commercial spaces can be increased appropriately so that the pedestrian flow of the commercial street can be directed to the entrances and exits of the commercial blocks below.

Finally, additional research is needed on the factors and indicators that influence the use of commercial space in station complexes. For example, the use of commercial space in station complexes is also affected by the organisational structure of various types of urban transport spaces and the urban transport sharing rate of different stations. In addition, this study focuses on analysing the layout of commercial space in station complexes from the perspective of "node-path", and abstractly expresses the use of commercial space as the total flow of people at all entrances and exits and the flow of people at all entrances and exits, which is only one aspect of measuring the effect of the use of commercial space, and can be measured by choosing more detailed indicators such as the flow of people entering stores. metrics such as inbound foot traffic to measure, and can also be supplemented with weekend foot traffic data for comparative studies with weekday usage. In addition, if the number of traffic-type passengers is increased excessively, it may affect the efficiency of passengers entering and leaving the station, and in the actual planning and design process, it is necessary to consider the balance and conversion of both traffic dispersion and commercial agglomeration.

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