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Impacts on passenger flow in condition of new line access in urban rail transit network

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Abstract
With the rapid development of urban rail transit, different new lines will be put into operation every year in the future, and many cities will change from the original single-line operation to the new stage of networked operation. Based on the functional positioning and access location of the new line, this paper studies the types of new lines accessing existing networks, and analyzes the impact of different new line access types on passenger flow and network passenger flow in neighboring stations. By analyzing the composition of rail transit passenger flow after the new line is connected, the reasons for the change of passenger flow after the new line is connected are studied. Finally, the influence law of the new line access on the network passenger flow is studied in combination with the specific case of Shenzhen rail transit.

Keywords: urban rail transit; new rail accession; new line type; network passenger flow

1. Introduction
Since the beginning of the 21st century, China's urban rail transit industry has entered a period of rapid development, and different new lines will be built and put into operation every year. As of December 31, 2017, 34 cities in China have opened urban rail transit, and there are 165 urban rail transit lines in use [1]. Shenzhen has formed a total of 8 operating lines on lines 1, 2, 3, 4, 5, 7, 9, and 11 through a four-wheel rail transit construction plan, with a total length of 286 kilometers of orbital operation network. Therefore, in order to better analyze the changes of passenger and network passenger flow distribution after the new line access, it is very necessary to study the impact process and internal mechanism of the new line access on the passenger flow of the rail transit network.

2. Type of new line access road network
In order to study the impact of the opening of the new line on the existing network passenger flow, it is first necessary to analyze the type of new line access. According to the geographical layout of the new line, the function positioning of the new line and the connection relationship between the new line and the existing network, the new line access types are divided into two categories: introduce new lines into existing wired networks and build extension lines on existing wired networks.

2.1 Introducing new lines
2.1.1 Regional through line
The regional through-type line generally refers to the line connecting the two ends of the city, running through the central area of the city and most of the stations are located in the urban area [2]. For example, Line 2 of the Shenzhen Metro, which runs from SK in the west, passes through the NS Commercial District and the FT Central District, and eventually extends to the LH District. The line has a total of 9 transfer stations connected to other lines, which are typical regional through lines.

2.1.2 Regional ring line
The regional ring line refers to the line connecting the functional areas of the central city and connecting the core area of the central city with the edge area through the regional through-type line. The regional ring-type line generally has better network connectivity, has more transfer stations, and has high network connectivity. The access of such new lines has the greatest impact on the existing network structure, and often plays the role of aggregation and dispersion. For example, Shenzhen Metro Line 5 goes west to LH, north to SZB, and east to BGL, which together with Lines 1 and 2 on the south side form a regional loop.

2.1.3 Suburban connecting line
Suburban connection refers to the line connecting the central city and the suburban new city. The general passenger flow of such lines has obvious directionality. The early peak is the passenger flow into the city, the late peak is the passenger flow out of the city, and the highest section appears on the nearest interval of the access network. The suburban connection line generally accesses the existing network through a single or multiple transfer stations, and its access has little influence on the structure of the existing network, and mainly plays a role of aggregation. For example, Shenzhen Metro Line 3 and Line 11 are typical suburban connections.

2.2 Extension line of existing line
Some lines may have too long lines during planning, and the passenger travel demand at both ends of the line is not very large. In order to ensure the operational efficiency of the enterprise and the rational use of construction funds, the rail transit line usually adopts the strategy of “scheduled

construction and segmentation operation" [3]. As the city expands outward, the travel needs of residents increase greatly, and it is necessary to extend the existing routes appropriately. The extension lines of the existing lines are mainly divided into two types: the urban central area extending to the suburbs and the inner extension of the city.

2.2.1 Suburban extension line

The extension line of the suburbs mainly extends to the periphery of the city on the basis of the current line, such as the extension line of Lines 2, 3, 4 and 5 under construction of the Shenzhen Metro.

2.2.2 Urban extension line

The extension line in the urban area refers to the extension and renewal of certain lines within the city, such as the extension line of the Shenzhen Metro Line 9 under construction.

3. Analysis of the impact of different types of new line access on network passenger flow

3.1 Analysis of the impact on passenger flow in neighboring stations

The impact of the opening of new lines on the passenger flow of existing line stations can generally be divided into two categories: One type is splitting, that is, the new line has a competitive relationship with the existing line, sharing part of the wired passenger flow, resulting in the decline of the existing passenger flow; The other type is induced, that is, after the opening of the new line, it will inevitably attract residents around the new line site to take the city rail transit, bringing more passengers to the existing cable network. The process of diversion and induced passenger flow changes as shown in Figure 1 and Figure 2.

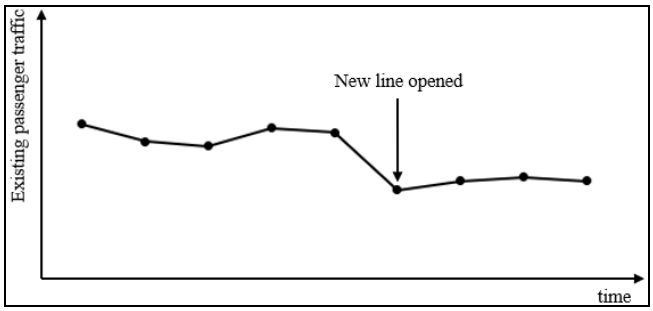

Fig 1: Passenger flow diversion process.

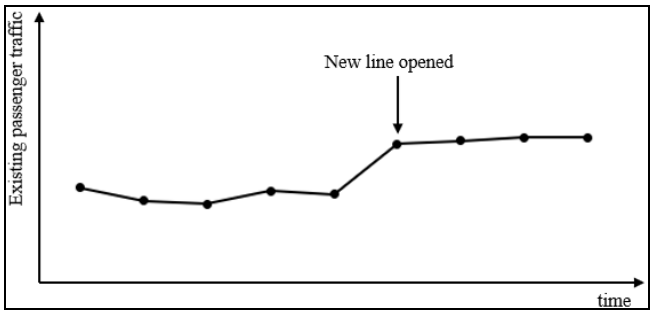

Fig 2: Passenger flow induced process.

3.1.1 Passenger flow diversion

If the new line is parallel to the existing line and the distance between the new station and the existing website point is close enough, the passenger's path selection range will be increased, and the passenger flow will be diverted, resulting in a decrease in the passenger flow of the existing line [4]. For example, the upcoming part of the subway line 6 and 10 in Shenzhen will be parallel to the original line 4, as shown in Figure 3.

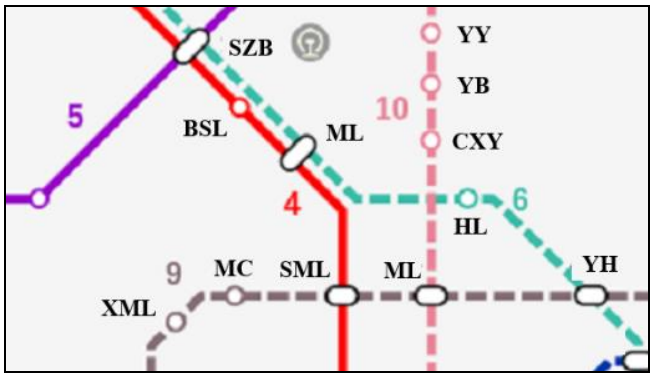

Fig 3: Shenzhen Metro Line 4, Line 6 and Line 10.

3.1.2 Passenger flow inducement

The newly opened urban rail transit line will generate many new sites. For the non-urban core area where the urban rail transit network is loosely distributed, the opening of the new site will stimulate the travel demand of nearby residents and generate trapped passenger flow [5]. For example, Shenzhen Metro Line 7 intersects Line 2 and Line 5, making the ATS Station and XL Station intersected by the intermediate station into a transfer station. After the opening of Line 7, the passenger flow of the station at XL Station increased by 32%, and the passenger flow at the station of ATS Station increased by 90%. The change of passenger flow in the station is shown in Figure 4.

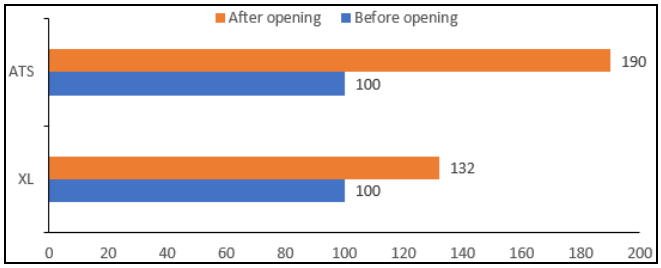

Fig 4: Passenger flow changes at XL Station and ATS Station.

3.2 Analysis of the impact of the opening of the new line on the total passenger flow of the network

Urban rail transit has a long construction period and huge investment costs. In order to ensure the reasonable investment of funds into the construction of rail transit, the construction order of each line is often arranged according to the functional positioning of the line [6]. Since the opening of the first line of the Shenzhen Metro on December 28, 2004, the annual passenger traffic has been on the rise. As of 2018, the current passenger volume of the Shenzhen Metro has reached 1.637 billion passengers, which is 12 times higher than the 135.5 million passengers ten years ago, as shown in Figure 5.

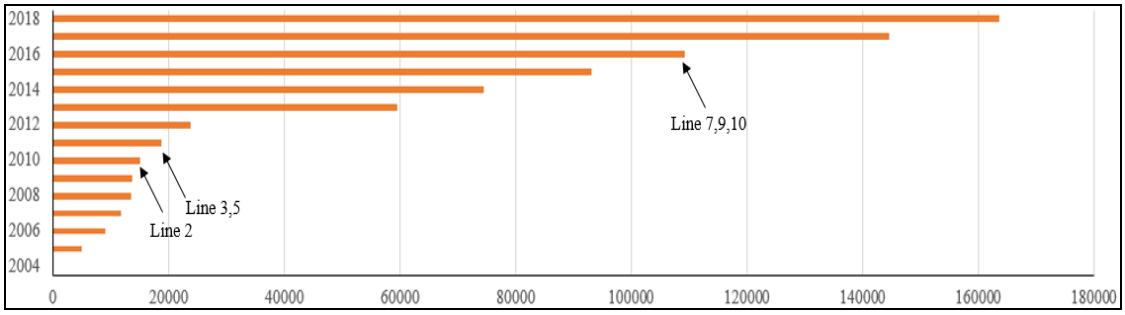

Fig 5: Shenzhen Metro's annual passenger traffic.

3.2.1 Expanded service scope
With the continuous construction of rail transit, the scale of the network will continue to expand. For example, Line 10, which is being built by the Shenzhen Metro, will connect Hong Kong and Dongguan, allowing passengers to travel between nearby cities via convenient urban rail transit.

3.2.2 Service level improvement
With the continuous improvement of the network, the stations of the rail transit will be more dense, and passengers can transfer to any corner of the city through several transfers. With the completion of the extension of Line 9, it will enable more passengers to take the subway to their destinations within a smaller traffic radius and attract more passengers from other modes of transportation to transit.

4. Reasons for changes in passenger flow after new line access
4.1 Analysis of the composition of passenger flow in rail transit
After the new line is connected, the rail transit passenger flow is mainly composed of three parts: basic passenger flow, transfer passenger flow and induced passenger flow.

4.1.1 Basic passenger flow
There is a certain stability in the passenger flow of urban rail transit, but due to seasonal changes and the growth of passenger flow itself, there will be some fluctuations in passenger flow. This part of the passenger flow can be predicted and estimated by a time series model.

4.1.2 Transfer passenger flow
The transfer of passenger flow refers to the flow of passengers transferred by other modes of transportation after the opening of the new rail transit line. The transfer of passenger flow generally consists of two parts, one is the passenger flow that chooses the conventional bus or bicycle transportation mode, and the other is the passenger flow transferred from the car [7].

4.1.3 Inducing passenger flow
Inducing passenger flow means that with the opening of the new line, it stimulates residents to generate new travel demand, which increases the intensity of residents' travel, thus creating a trapped passenger flow [8]. After the opening of the new line, the land use development intensity around the line is generally longer than that of the new line construction period. At this time, the induced passenger flow is relatively small, and the transfer passenger flow is the main component of the new line passenger flow, and the passenger traffic transferred to the rail transit is the largest. It can generally account for 60% to 80% of the total passenger traffic of the new rail transit line [9].

4.2 Analysis of the causes of passenger flow changes
4.2.1 Changes in the nature of land use along the route
With the continuous access of the new line, more population and post aggregation effects will be obtained near the new line station, and the development and utilization of land along the line will be enhanced. For example, Shenzhen Metro Line 11 will contact Hong Kong, Guangzhou, Dongguan, Zhongshan, Maoming and other places in the future, which will greatly change the land use situation along the route. As of December 2018, the average daily passenger traffic of Shenzhen Metro Line 11 has increased from 208,100 in the initial period to 429,400.

4.2.2 The expansion of the network passenger flow attraction
With the uninterrupted opening of the new line, the scale of the entire rail transit network will become larger and larger, and the range of passenger flow attraction of rail transit will continue to expand [10]. Taking the Shenzhen Metro as an example, as of August 2017, the Shenzhen Metro has opened 8 lines with a total of 199 stations, and the total length of the city's subway lines is 285 kilometers. By 2020, the Shenzhen Metro will form 16 operating lines with a total length of 597 kilometers of rail transit network, and its network attraction will be greatly improved.

4.2.3 Increased connectivity of rail transit network
The opening of the new line will change the structure of the rail transit network, so that the connectivity between the nodes of the rail transit will be enhanced, and the passengers' travel routes in the rail transit network will have more obvious diversity due to different transfer options. For example, with the opening of Shenzhen Metro Line 7, Line 9 and Line 11, the HH, ATS, JT and HQB intermediate stations in the existing cable network will become transit stations, which will greatly facilitate passengers to choose shorter and more Good path.

5. Case analysis
As of 2018, the new types of railway lines opened in Shenzhen in the past three years are all regional ring lines and suburban connecting lines. Therefore, combined with the status quo of the development of rail transit in Shenzhen, this paper mainly analyzes the impact of the opening of regional ring-type and suburban connecting lines on the passenger traffic, transfer volume and cross-section passenger flow of the existing cable network.

5.1 Influence of regional ring line on passenger flow of wired network

5.1.1 Impact of the opening of Line 7 and Line 9 on the passenger traffic volume of the existing line

The opening of the regional ring line generally causes an increase in the number of transfer stations, which in turn causes the redistribution of passenger flow in the network, which has a greater impact on the OD distribution and the choice of passenger travel paths. After the access of Shenzhen Metro Line 7 and Line 9 on October 28, 2016, the average daily passenger traffic of the Shenzhen Metro increased by 19.98% in November, and the average daily passenger traffic of the entire network rail transit reached 4,216,300, accounting for the city's public. The traffic volume of the transportation system is 41.5%. Taking Line 2 as an example, in November, the average daily passenger traffic of Line 2 increased by 9.8%, the largest increase among all existing lines. Table 1 lists the passenger flow of Line 2 after the access of Line 7 and Line 9 influences.

Table 1: Impact of regional ring line access on passenger traffic on Line 2

	Inbound traffic	Exchange passenger traffic	Boarding traffic	Swap in passenger flow
Before opening	281,000	164,300	445,300	36.89%
After opening	347,200	234,400	581,500	40.30%
Rate of change	23.56%	42.67%	30.59%	9.24%

5.1.2 Impact of the opening of Line 7 and Line 9 on the transfer of existing lines

The access of the new line will cause an increase in the passenger flow of the transfer line transfer station, and then gradually affect the 1 extension station, 2 extension station and so on. Combined with the current situation of the construction of the Shenzhen Metro, taking Line 2 as an example, HQB Station and ATS Station are selected as the main interchange stations, then the extension station is SMZX station, and the second extension station is FT station. After the opening of the new line, the passenger flow at SMZX Station adjacent to HQB Station dropped significantly. The main reason is that there is a parallel relationship between the 7th and 4th lines, and there is a diversion effect on Line 4. For the FT Station of the Second Extension Station, the passenger flow has increased significantly. With the opening of the new line, the stations of ATS, JT, SX and HQB changed from ordinary stations to transfer stations, which increased the passenger flow at FT Station. The changes are shown in Table 2.

Table 2: Changes in the transfer amount of key transfer stations on Line 2 after the opening of Lines 7 and 9

Transfer station		Daily average daily transfer		
		Before opening	After opening	Rate of change
Main transfer station	HQB	-	8,492	100%
	ATS	-	52,663	100%
1 extension station	SMZX	55,928	49,511	-11.5%
2 extension station	FT	96,572	110,872	12.9%

5.1.3 Impact of the opening of Line 7 and Line 9 on the passenger flow of the existing section

After the new line is connected, the impact on the passenger flow of the adjacent section is first, for the existing line connecting with the new access line, the change of the cross section caused by the transfer station and the swapping out; and the second is to change the cross-section passenger flow caused by the shunting for the existing line parallel to the new access line; the third is to change the passenger flow of the section through the re-distribution of other existing lines for the unconnected line. After the opening of Shenzhen Metro Lines 7 and 9, the largest section of the 3rd line weekend changed from SB to CP to TB to SB, and the largest section of Line 5 during the peak hours of workdays became BX to TA. The maximum cross-sectional passenger flow during peak hours is shown in Table 3.

Table 3: Impact of the opening of Lines 7 and 9 on the maximum section of the peaks of Lines 3 and 5

Interval	Maximum section passenger flow	Average hour congestion	Rate of change
CP - SB	40,763	138.76%	11.4%
BX - TA	24,202	87.8%	6.34%

5.2 The influence of the suburban connection line on the passenger flow of the existing cable network

5.2.1 Impact of Line 11 on the passenger traffic volume

After Line 11 is connected to the existing network, the passenger flow of the entire network increases significantly. Taking daily average passenger traffic as an example, Line 1 increased by 5.69%, Line 2 increased by 6.57, Line 3 increased by 14.88%, Line 4 increased by 7.60%, and Line 5 increased by 8.53%. The specific data is shown in Table 4.

Table 4: Impact of line 11 access on passenger traffic volume

Average daily passenger traffic	Line 1	Line 2	Line 3	Line 4	Line 5	Whole network
Before opening	1,089,500	417,900	656,200	547,700	636,400	2,814,200
After opening	1,151,500	445,300	753,900	589,300	690,700	3,247,500
Rate of change	5.69%	6.57%	14.88%	7.60%	8.53%	14.13%

5.2.2 Impact of Line 11 on the passenger flow of the existing interchange station

Taking the daily average passenger flow of each interchange station in the month before and after the access to Line 11 as an example, except for HZZX, SJZC, and BAZX Station, the other transfer stations increased. The largest increase in the chain was in QHW and FT stations, with the increase of 376.12% and 128.81% respectively. The specific data is shown in Table 5.

Table 5: Changes in passenger flow on the transfer station after the access to Line 11

Transfer station	Daily average passenger traffic		
	Before opening	After opening	Rate of change
SJZC	118,600	113,400	-4.38%
BAZX	125,200	122,100	-2.49%
HZZX	219,700	218,200	-0.68%
QHW	20,200	96,100	376.12%
FT	53,100	121,600	128.81%
SNG	73,700	95,400	29.47%

5.2.3 Impact of Line 11 on Passenger Flow in Existing Lines

In the first month after the opening of Shenzhen Metro Line 11, the maximum daily passenger flow of the No. 2 line reached a record high of 25,570 person/hour, and the maximum passenger flow of the largest section of other lines decreased from the historical maximum. By analyzing the comparison of the maximum cross-section passenger flow in each operation chart interval on the working day of Line 2, it can be found that the maximum cross-section passenger flow and congestion degree of Line 2 are consistent, showing typical morning and evening peak double-peak patterns. Detailed data are shown in Figures 6.

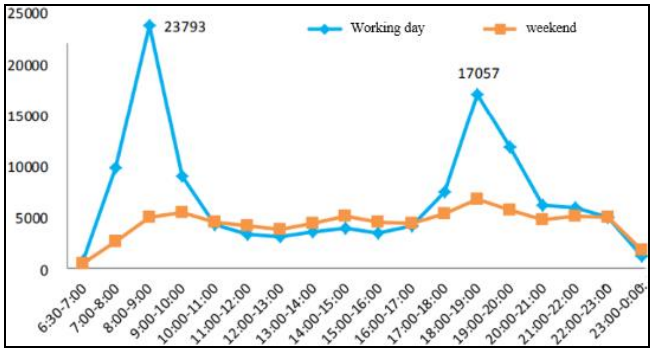

Fig 6: The maximum cross-sectional traffic of each operation chart in Line 2.

6. Conclusions

Urban rail transit passenger traffic tends to be large, and the passenger flow brought about by the opening of new railway lines often has a greater impact on the existing lines. In the case of a wired network, this impact will present a more complex pattern. In the network operation phase, study the new line access type, analyze the influence mechanism of different new line access types on the passenger flow of the existing cable network and the reasons for the passenger flow change, and formulate and adjust the new line design plan comparison and urban rail transit passenger transport organization plan. In order to deal with the impact of the new line passenger flow has an important role.

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