

Research on The Combined Operation Mode of Express-local Train in Urban Railways

-- Taking Wenzhou Rail Transit Line S1 as an Example

Yujun Pan*, Lihong Yang

School of Ruian, Wenzhou Polytechnic, Wenzhou, 325000, China

Abstract: The applicability of the combined operation mode of express-local train trains is analyzed. The express-local train without overrun scheme and the express train overrun scheme are studied. The influence of different express-local train schemes on the line capacity is analyzed. The setting method of express train non-stop and express train overrun station is determined. Finally, taking the Wenzhou Rail Transit Line S1 as an example, combined with the actual passenger flow data and travel plan data, the express-local train operation plans under different express and local train ratios are determined. It provides a reference for enterprises to operate express-local train trains.

Keywords: Express-local Train, Urban Railways.

1. Introduction

The express-local train mode refers to an operation organization mode in which two types of trains that stop at the station and stop at the cross-station are combined with a certain operating ratio. It can better meet the requirements of long-distance passengers to travel quickly, and thus, the fast and slow mode can better adapt to the different travel needs of different passengers.

Due to the different travel speeds, trains that stop at stations are called local trains, and trains that stop across stations are called express trains. The express-local train mode can meet differentiated services: it not only meets the needs of station coverage along the line, but also meets the needs of long-distance travel passengers to arrive quickly.

The passenger flow in the express-local train mode is uneven in time and space, and the line mileage and the average station distance for express and local trains are usually long. Practical experience shows that the mileage of existing express-local trains at home and abroad is over 45 kilometers, and the average distance between stations is usually 3 to 6 kilometers.

2. The Basic Theory of Express-Local Train Mode

2.1. Applicable

The implementation of the express-local train plan first needs to analyze the passenger flow. Only when the spatial and temporal distribution characteristics of passenger flow are suitable for express-local trains can the scheme give full play to its advantages and avoid disadvantages, so as to better serve passengers with different travel needs.

2.1.1. Time Distribution Characteristics of Passenger Flow

Different time distribution characteristics of passenger flow will have different impacts on the express-local train scheme. If the passenger flow of certain ODs in a certain time period is extremely large, it can be considered to operate more corresponding express trains in this time period to meet the

needs of passengers travel needs. If the passenger flow is evenly distributed in time and there is no obvious peak, it may be considered to implement the express-local train mode at all times throughout the day. Therefore, it is necessary to analyze the time distribution characteristics of the passenger flow of the line in detail when formulating the express-local train plan, and then determine the running time period of the express-local trains on the line or adjust the running ratio of the express-local trains based on this.

2.1.2. Spatial Distribution Characteristics of Passenger Flow

The passenger flow of line services with different positioning usually also has different spatial distribution characteristics. When considering the express-local train scheme, it is necessary to combine the line positioning to analyze the spatial distribution characteristics of passenger flow, such as passenger flow cross-section and passenger flow direction. If the passenger flow of each station is similar, the express-local train plan is not suitable. If there are obvious large and small passenger flow stations on the similar line, it is suitable to run express trains between the large passenger flow stations to improve the passenger flow travel efficiency of the large passenger flow stations, and then use the local train to provide travel services for the small station passenger flow with a small number.

In the direction of passenger flow, because the passenger flow itself has a direction, the upstream and downstream passenger flows are often different in the same time period, or even quite different. Generally, it can be expressed by the unbalanced coefficient of passenger flow γ .

$$\gamma = \frac{\max \{ q_{\max}^{\text{up}}, q_{\max}^{\text{down}} \}}{(q_{\max}^{\text{up}} + q_{\max}^{\text{down}}) / 2}$$

Where q_{\max}^{up} is the maximum cross-section passenger flow of the upward [person/h], and q_{\max}^{down} is the maximum cross-section passenger flow of the downward [person/h]. $\gamma > 1$, and the larger the value is, the driving plan needs to be formulated separately for the up and down.

2.2. The Express-local Train Plan

2.2.1. No Overrun Express-local Train Plan

No overrun express-local train refer to express trains that do not stop and pass at some stations with a small passenger and drop capacity. Since there is no overtaking behavior, the line is generally two-lane, and the express train and the local

train share the line, which has little impact on the passing capacity of the line. During the operation of this scheme, it is necessary to ensure that the tracking interval between the trains in the section and the station is less than the minimum tracking interval. The scheme of express-local trains without overtaking is shown in Figure 1.

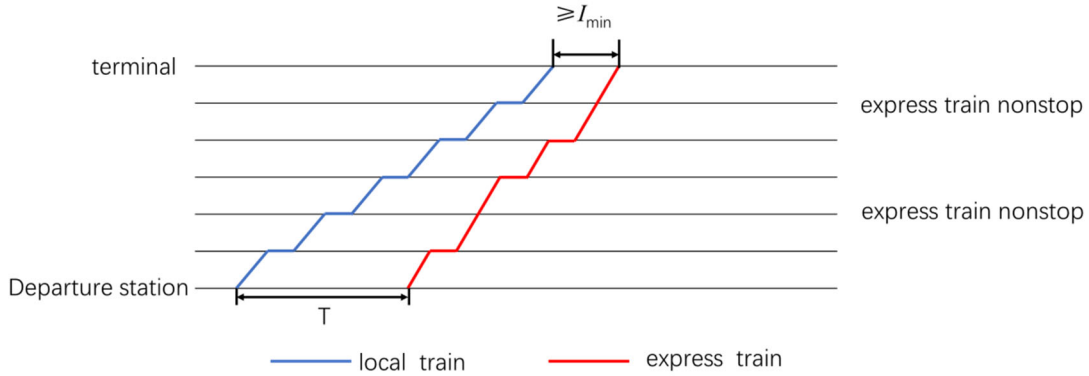


Figure 1. The schematic diagram of no-overtaking express-local train scheme

Since some stations of the backward express train do not stop, the travel speed is increased, so that the tracking interval between the backward express train and the forward slow train is reduced. Since the forward local train is not overtaken, in order to ensure the safe operation of the train, the arrival interval of the front and rear trains at the terminal station needs to be guaranteed at least is the minimum tracking interval.

2.2.2. Express Train Overtaking Plan

The express train overtaking and local train scheme requires the line to have the train overtaking capability.

According to the position of the express train overtaking the local train, it can be divided into two forms: section overtaking and station overtaking. Section crossing requires the crossing section line to be more than two lines. If the station overruns, the overrunning station needs to have the ability to overrun. Generally, it can be set up as a station with two island platforms and four traffic lines. However, when the station overruns, the local train needs to wait for the express train to overrun to prolong the stop time of the local train. Therefore, the station overrun has a greater impact on the local train and the capacity of the line. The schematic diagram of the station crossing is shown in Figure 2.

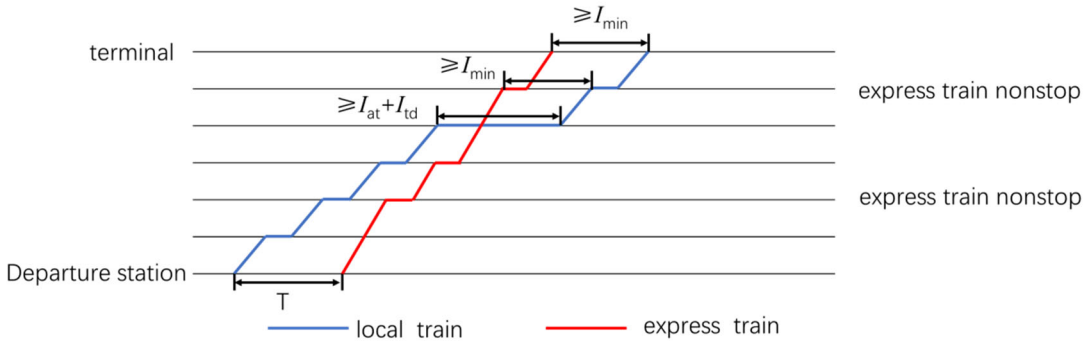


Figure 2. The schematic diagram of express train overtake local train

2.3. Influence of Express-local Train Scheme on Line Capacity

The impact of express trains overtaking local trains at stations is determined by various tracking interval constraints. The minimum tracking interval is the minimum time interval during which the preceding and following trains run according to the operation plan without affecting each other. Urban rail transit lines are generally double-track. Therefore, for the lines laid out by two lines in the interval, the minimum driving interval of urban rail transit can be expressed as the sum of the maximum stopping time and the minimum tracking interval. The biggest influencing factor of the line's

passing capacity is the line's minimum driving interval. With the minimum tracking interval of 90s, the research and discussion are carried out on different stop times and the ratio of express-local trains.

Referring to the regulations of subway design code (GB50157-2013), take the minimum train station arrival interval $I_{da}=90s$, when the stop time $t_z=30s$, the minimum travel interval at this time is $I_{aa}=I_{dd}=I_{da}+t_z=120s$, corresponding to the traffic density is 30 columns/h. I_{aa} and I_{dd} are the sum of the minimum tracking interval and stopping time. The values of various tracking intervals used in the other combined optimization models are shown in Table 1.

Table 1. Various tracking interval values

Parameter Name	Meaning	Value
I_{da}	At the same station, the minimum departure time between the departure of the preceding vehicle and the arrival of the following vehicle.	90s
I_{dt}	At the same station, the minimum time between the departure of the preceding car and the passing of the following car without stopping.	150s
I_{ta}	At the same station, the minimum pass-to-arrival interval for the preceding vehicle to pass without stopping and the following vehicle to arrive.	120s
I_{at}	When overtaking occurs, the minimum time between arrivals of the preceding vehicle and overtaking of the rear vehicle.	60s
I_{td}	When overtaking occurs, the minimum passing interval for the preceding vehicle to overtake and the rear vehicle to depart.	90s

When running express-local trains, the formula for calculating the capacity of urban rail transit lines is as follows.

$$n_{max} = \frac{3600}{T'} * (\frac{f_1}{f_2} + 1)$$

$$T' = (\frac{f_1}{f_2} + 2) * I_{min} + (\frac{f_1}{f_2} - 1) * tz$$

Where f_1 is indicates the frequency of local departures [columns/h], and f_2 is indicates the frequency of express departures [columns/h], and tz is stop time[s].

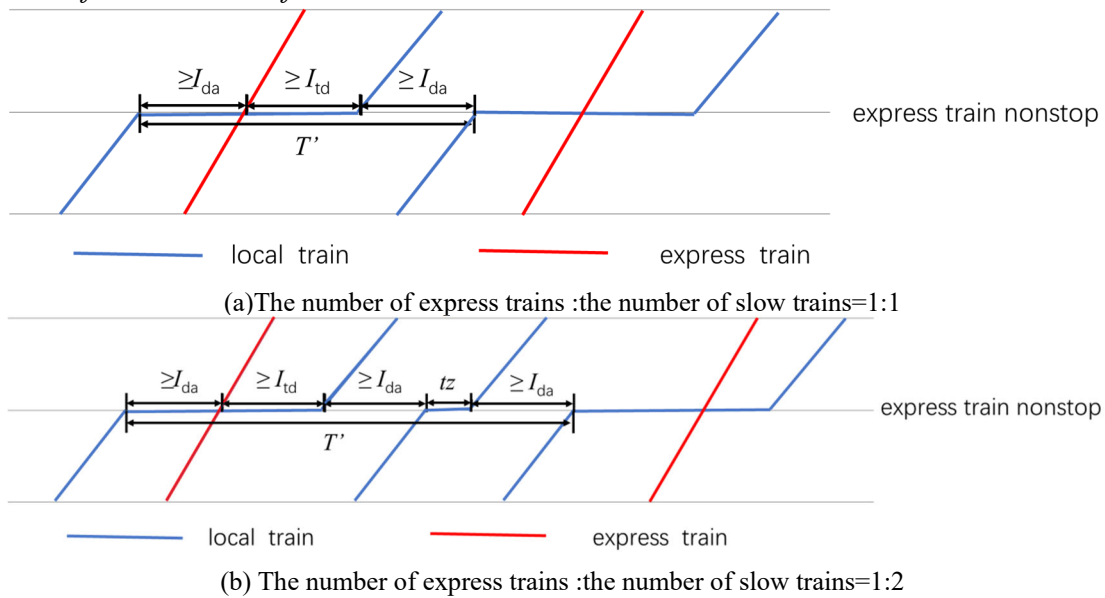


Figure 3. Rail capacity of express-local train

Table 2 shows the calculation results of the line passing capacity under the conditions of different stop times of local trains at overpassing stations and different ratios of express-local trains.

Table 2. Rail capacity under different station dwell time and departure ratio of express-local train

$f_1:f_2$ tz	1:1	2:1	3:1	4:1
30	26	27	28	28
35	26	27	27	27
40	26	27	27	27
45	26	26	26	26
50	26	26	26	26
55	26	26	25	25
60	26	25	25	25

2.4. Setting of Non-stop and Over-travel Stops for Express Trains

2.4.1. Express Train Non-stop Station

By reviewing literature and referring to actual operating experience, it is concluded that express train stops should be set up at stations with an average daily passenger drop of more than 100,000 passengers, and express trains at stations with an average daily passenger drop of less than 50,000 passengers may not have a stop. The above experience can be used for verification and comparison after generating the scheme. The optimal non-stop express train scheme for different lines should be calculated according to the passenger flow distribution of different lines.

2.4.2. The Overpass Station

Regarding the setting of overpassing stations, firstly, it should be judged whether the express train needs to overtake the local train at a certain station in front of the terminal, and then the position of the overpassing station should be judged

according to the tracking interval between express trains and local trains at each station.

According to whether the arrival interval of the following express train and the preceding local train at the terminal satisfies the minimum tracking interval, it is determined whether the express train needs to overtake the local train. When the tracking interval between the following express train and the preceding local train at the terminal is less than the minimum arrival interval, that is $T < I_{min}$. At this time, the express train needs to cross a certain station before the terminal and proceed to the local train.

The selection of the overpass station is determined according to the tracking interval, and the overpass situation is shown in Figure 4.

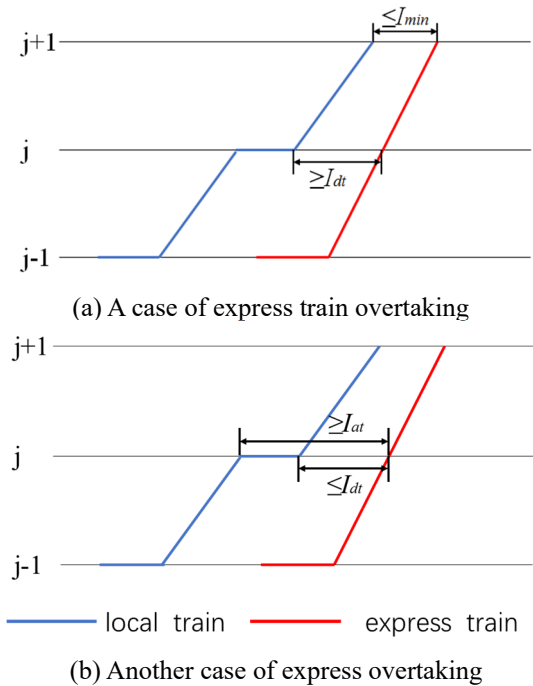


Figure 4. Different situations of express train overtaking

A case of overtaking express trains means that the tracking interval

interval between the express train and the preceding local train at station j satisfies the minimum train departure interval I_{dt} , but the tracking interval at station $j+1$ does not meet the train minimum arrival interval I_{min} . Station j traverses the slow train. Another situation of express train overtaking means that the tracking interval between the express train and the preceding local train at station j satisfies the minimum train arrival interval I_{at} , but does not meet the train minimum departure interval I_{dt} . In this case, the express train needs to overtake the preceding local train at station j .

An overrun occurs when either of the two conditions is satisfied. And both situations occur when the express train does not stop. The location of the over-travel station can be generated after determining the non-stop plan for express trains, which has nothing to do with the distribution of passenger flow.

3. Take Wenzhou Rail Transit Line S1 as an Example

3.1. The Wenzhou Rail Transit Line S1

The Wenzhou Rail Transit Line S1 is the first urban rail transit line built and operated in Wenzhou. The west section of the first phase of the project (Tongling to Olympic Center Station) was opened on January 23, 2019, and the east section (Olympic Center Station to Shuang'ou Avenue) was opened on September 28, 2019. The Wenzhou Rail Transit Line S1 generally runs east-west, starting from Tongling in the west and ending at Shuang'ou Avenue in the east. It has a total length of 53.5 kilometers, and the length of the line meets the requirements for running express-local trains.

The line has 18 stations, including Tongling, Panqiao, South Railway Station, Xinqiao, Dezheng, Longxia Road, Huimin Road, Sanyang Wetland, Longteng Road, KeJiCheng, Yao Xi, Olympic Center, Yongzhong, Airport, Lingkun, OuJiangKou, Ouhua, and Shuang'ou Avenue. It adopts 4-car marshalling D-type trains, which are marshalled for municipal railways.

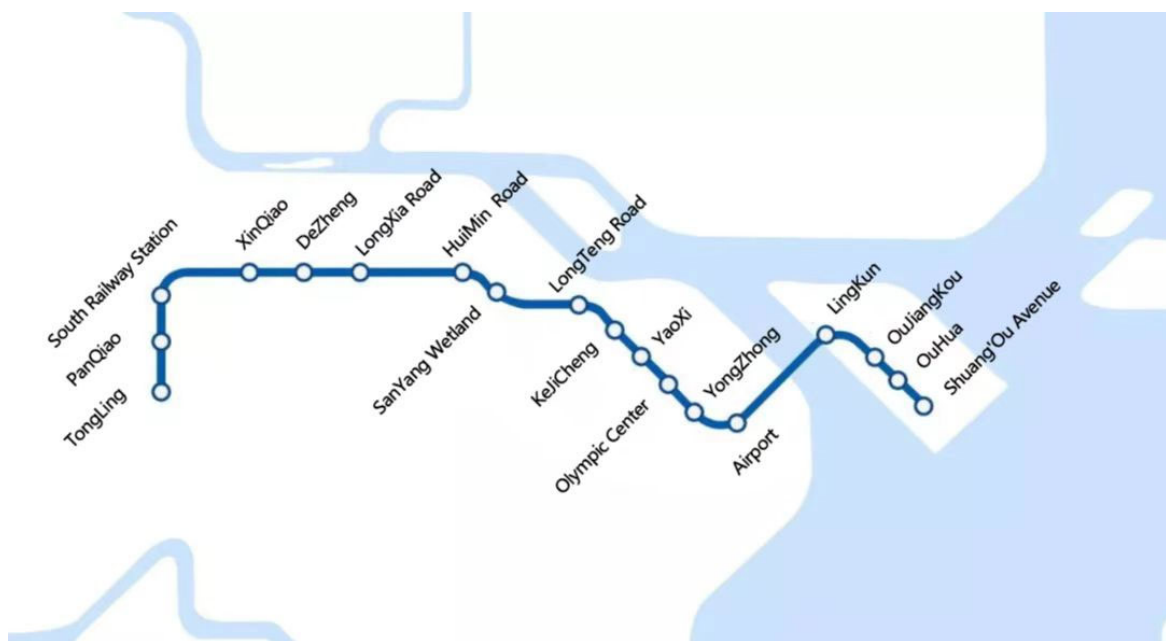


Figure 5. The Schematic diagram of Wenzhou Rail Transit Line S1

3.2. Passenger Flow Characteristics and Setting of Over-travel Stops

According to statistics, the full-day time-sharing passenger

flow data and cross-sectional passenger flow data of a working day in May 2022 are shown in Figure 6.

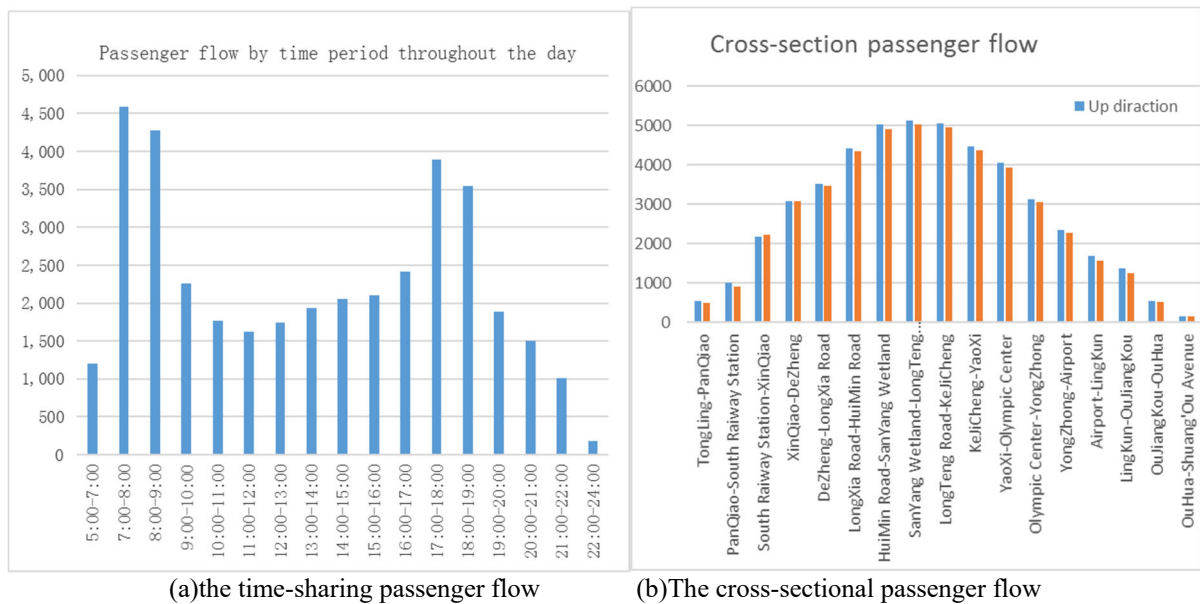


Figure 6. The time-sharing passenger flow and cross-sectional passenger flow of a working day

As can be seen from the above figure, the time distribution of passenger flow is uneven, and the combined operation mode of express-local trains can be implemented in the morning peak at 7:00-9:00 and in the evening peak at 17:00-19:00. The upward and downward distribution of passenger flow in the section is relatively balanced, and both are convex. Therefore, the same fast and slow train scheme can be

adopted for the upward and downward. In addition, non-stop express trains can be set up at the stations at both ends, and express train stops can be set up at the middle station. The route map of Wenzhou Rail Transit Line S1 is shown in the figure below. According to the previous research, only two stations can be set as overtravel stations, they are LongXia Road and LongTeng Road.

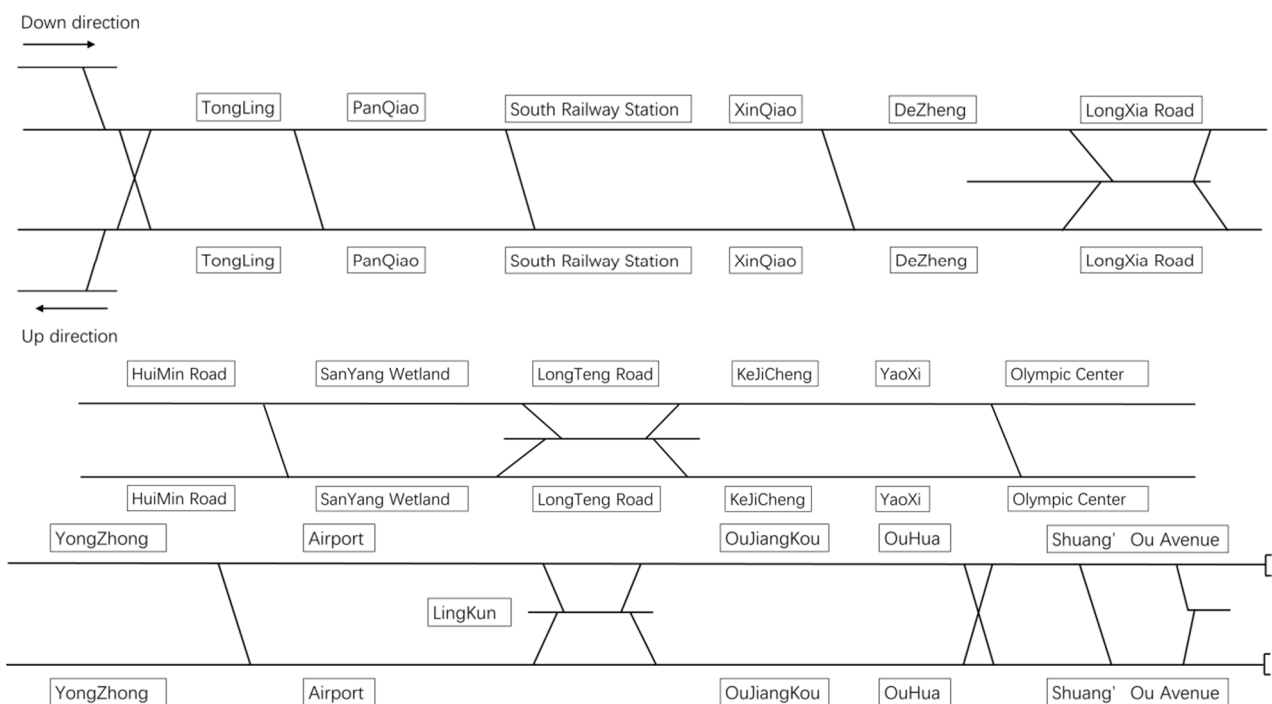


Figure 7. The route map of Wenzhou Rail Transit Line S1

3.3. The Express-local Train Operation Plan

3.3.1. Basic Assumptions

(1) The trains run at a fixed time interval, and all use a single route. Express trains do not stop at stations with less passenger traffic, while local trains stop at stations.

(2) Express trains overrun the local train at the station, the local train waits at the overrun station to the auxiliary line, and the express train enters the station directly at the overrun station.

(3) The number of trains on the whole line, the type of trains and the speed limit of each station are the same, and the

additional time for starting and stopping of trains in each section adopts a unified standard.

(4) Except for some local trains that need to extend the stop time due to avoiding express trains at over-travel stations, the rest of the trains strictly abide by the stop time standard.

(5) Express trains cannot overtake adjacent express trains at two consecutive stations.

3.3.2. The Known Parameters

The known parameters are shown in Table 3. The station number is set to 1 for TongLing and 18 for Shuang'Ou Avenue.

Table 3. Value of Known parameters in case

Parameter Name	Meaning	Value
TR	Study period	7:00-8:00, 7200s in total
N	Number of Stations on S1	18 stations
v	Train speed	22.22m/s
a1	Train start acceleration	1m/s ²
a2	train braking acceleration	1.1m/s ²
T(Turn back)	Train turnaround time	240s

Table 4. Station dwell time and station spacing of Wenzhou Rail Transit Line S1

station number	1	2	3	4	5	6	7	8	9
Stop time/s	60	35	50	35	35	35	35	35	35
Station spacing/m	2286	3050	5880	2243	1947	2730	1873	5271	2179
station number	10	11	12	13	14	15	16	17	18
Stop time/s	35	35	50	35	50	35	35	35	60
Station spacing/m	3043	3892	1841	2247	7087	3583	1850	2005	

3.3.3. The Express-local Train Plan

At present, the interval between the morning peak hours of the S1 line is 600s. Taking the morning peak period from 7:00 to 9:00 as the research period, analyze the running plan when the ratio of local trains and express trains is 1:1, 2:1, 3:1, and 4:1 respectively. Due to the long interval between trains,

combined with the passenger flow data analyzed above, if the express trains do not stop at the two stations, and the express train stops at the middle station. After checking, the express train can meet the minimum tracking interval without overtaking the local train. Therefore, the final combined operation mode of express-local trains is shown in Table 5.

Table 5. The express-local train plan

the ratio of local trains and express trains	Departure interval /s	local train departure frequency y	express train departure frequency	Number of non-stop express trains	Station number where the express train does not stop	local travel time/s	express travel time/s
1:1	600	6	6	8	2/3/4/13/14/15/16/17	3576	2983
2:1	600	8	4	8	2/3/4/13/14/15/16/17	3576	2983
3:1	600	9	3	8	2/3/4/13/14/15/16/17	3576	2983
4:1	600	10	2	8	2/3/4/13/14/15/16/17	3576	2983

When the driving time interval is less than 460s, overtaking will only occur. At this time, LongXia Road or LongTeng Road can be selected. At this time, the travel time of the local train will be extended, and the travel time of the express train will remain unchanged.

4. Conclusion

Firstly, the applicability of the combined operation mode of express-local trains is analyzed, and different combined

operation modes of express-local trains are proposed respectively for the unbalanced temporal and spatial distribution of passenger flow. After that, the express-local train schemes are studied, including the no-overrun express and local train scheme and the express train overrun scheme. After that, the influence of different express-local train schemes on the line passing capacity is analyzed, and the settings of non-stop express trains and express train overtravel stops are determined. Finally, taking the Wenzhou Rail Transit Line S1 as an example, combined with the actual

passenger flow data and travel plan data, the express-local train operation plans under different speed and local train ratios are determined, which provides a reference for enterprises to operate express-local trains.

Acknowledgment

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