Optimal Bus Route Planning for Rail Station Based on Rail Network

Chaohui Wang[1], Shanshan Yu[1], Juanjuan Kong[2]

[1]Zhejiang Jiake Electronics Co., Jiaxing Zhejiang, 31400, China

[2]China Electronics Technology Group Corporation No.36 Research Institute, Jiaxing Zhejiang 31400, China

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Abstract: Based on the investigation data of passenger flow bus transfer features of a large number of rail stations in urban built-up areas, the passenger flow proportion of bus transfer in rail stations, the spatial distribution of passenger flow, as well as the attraction area of bus passenger flow were analyzed. Then relying on the rail network, bus routes optimization planning methods of rail stations were put forward, and the estimation methods for starting bus lines in rail station entrances and bus transfer facilities land via bus lines were provided.

1. Introduction

With the construction of rail transit, it has become one of the traffic problems that need to be solved urgently at present to realize the effective connection of various transportation modes at rail stations, intensify resources, improve the service level of the transportation system, and establish an efficient, safe, convenient and high-quality public transportation transfer system. Due to the late start of China’s rail transit construction compared with European and American countries, there is not only a lack of experience accumulation and theoretical guidance in the planning and design of rail station transfer facilities based on the rail network, but also sufficient in in-depth research on the cooperation between rail transit and surface buses, efficient connection and transfer, etc. In this paper, based on many years of investigation data of passenger flow transfer features in rail stations, the passenger flow proportion of bus transfer in rail stations, the spatial distribution of passenger flow, as well as the attraction area of bus passenger flow were deeply analyzed. On this basis, combining with the research results of rail transit integration and relying on the rail network, the bus routes planning methods of rail stations as well as the estimation methods for bus transfer facilities land were proposed.

2. Research on railstation-bus integration planning

In recent 10 years, as the algorithms to solve complex models have been continuously proposed and improved, such as simulated annealing algorithm, neural network algorithm, and genetic algorithm, the theoretical methods for the overall optimization of public transit network have been gradually improved. In 2005, Han Baoming and Xie Yujie et al from Beijing Jiaotong University studied the layout of ground conventional public transportation lines based on urban rail transit, the transfer layout of integrated passenger transport of urban rail transit and ground conventional public transportation, seamless transfer and ticket system coordination [5].In 2007, Shanghai Tongji University carried out a study on the rail-bus integration, and proposed the rail-bus integration strategy, supporting scale and construction standard of large rail-bus transfer hub lines, as well as the integration planning scheme of rail and ground bus network.

Among the above studies, some mainly focus on the discussion of typical rail transit hubs from the perspective of traffic designat the micro level, while others concentrate on the bus network optimization and the connection planning between bus and rail transit networksat the macro level. However, the research on the planning and design method of bus transfer facilities, which considers both the rail network layout at the macro level and the rail stations at the micro level as the starting point, has not formed a series of research results.

3. Bus route planning method of rail stations

3.1 Optimization method of bus route connection

Based on the characteristics of bus passenger flow transfer and relying on the rail network, the bus route optimization planning methods for rail stations are as follows:

(1) Adjust the starting and passing bus routes near the rail station by taking the rail network as the background.

Based on the relationship between the bus route direction and the rail network, the bus lines near the rail station can be divided into the following three categories: (1) The bus routes roughly coincide with single railway lines; ②The bus routes are parallel to or coincide with a few single railway lines; ③ The bus lines are vertical or intersecting with some single railway lines. For the first category of lines, when the bus line overlaps with a single railway line for more than 5 km(overlaps with the track station for more than 5 stops), the bus line and railway line will form a direct competitive relation. The main role of rail transit should be guaranteed by means of line merger, direction adjustment and vehicle allocation reduction. For the second category, the bus line station can be adjusted to the railway station entrance and exit, in order to meet the diverse needs of passenger flow transfer in the direction and mode; The third category of bus lines serve the main direction of the passenger flowtransfer, which can concentrate the first and last stations of the bus line to the railway station as far as possible by shortening the route direction and setting up regional buses, thus facilitating the connection and transfer of the two ways.

(2) Set up lightering lines to enhance accessibility.

Lightering lines are a special type of lines in bus network (Figure 1), which are mainly located on branch roads with a running distance of less than 8 km. Vehicles are usually small, and the route direction and stations are deep into living areas, schools, business districts and public activity centers, providing short distance passenger flow service from one end to the door. The capacity of a lightering line is about 2,500 to 3,500 times per day.

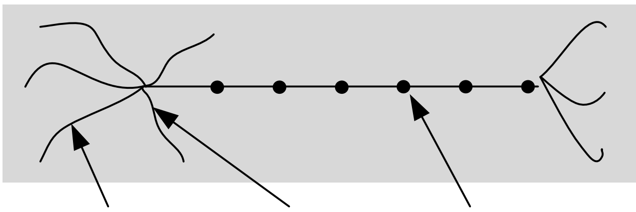

Fig. 1 Schematic diagram of setting up lightering lines at railway stations

According to the above analysis of the attraction range of rail stations, the bus lighering lines with a length of 6-8 km are set up around rail stations, which can not only meet the demand of bus-rail passenger flow transfer, but also change the transfer mode of passenger flow, so that the transfer passengers using some other ways (such as walking, bicycle, taxi) can use bus transfer. Besides, compared with other bus routes, lightering lines have some advantages such as flexible station setting and strong reliability, which are conducive to attracting potential transfer passenger flow and enhancing the attraction of public transportation.

3.2 Estimation method of bus route scale

The public transportation of railway stations is determined by many factors, including the number of bus routes, the number of assigned buses, the reserved space of transfer land for railway stations, as well as the setting of entrances and exits. First of all, a certain scale of bus transfer land is the precondition for rail-bus transfer, and the number of bus routes is the direct basis of transfer land reservation control; Secondly, the number of bus routes and the number of assigned buses directly determine whether the demand of passenger flow can be met, while other factors are correlated with the operation efficiency and indirectly meet the demand of passenger flow; Thirdly, the number of bus routes and the number of assigned buss are also the prerequisites for the transfer design of railway stations and the setting of entrances and exits. In this section, on the premise that the passenger flow demand C of bus transfer is known, through the investigation and analysis of the transport capacity of bus routes in peak hours, the estimation method of the number of bus routes meeting the passenger flow demand is studied, so as to provide a basis for the land control of bus transfer at railway stations.

The calculation method of the transport capacity of the existing bus routes is as follows: the transport capacity of the bus routes is determined according to the number of passengers that the bus routes can provide in a unit of time, that is, the full capacity of each bus is 1, and the maximum transport capacity of a bus line in peak hours is about 1 000 ~ 1 800 person-times. In the actual operation, it is often impossible for the full load rate of bus routes to reach 1, and the transportation capacity of the passing lines is also very different from the starting lines. When estimating the number of bus routes at railway stations, Formulas (1) and (2) can be used to calculate the transportation capacity of the routes.

Starting line: $C_{od}=60Rr/ti$ (1)

Where C_{od} is the transport capacity of the starting line, person-time/peak hour; R is the rated passenger capacity of the bus, with 65 passengers for the 10 m-long bus and 80 passengers for the 12 m-long bus; r is the load factor in peak hours; $t_i$is the departure interval in peak hours.

Unidirectional route: $C_o=60B/ti$ (2)

Where Co is the transportation capacity of one-way route, person-time/peak hour; B is the average number of passengers at the intermediate station during peak hours.

According to the survey, the average capacity of each bus on a starting bus route in peak hours is 23 ~ 32 people, and the full load rate is about 0.3 ~ 0.4 based on the rated full load of 80 people·bus^{-1}. r =0.4 is used in estimating the transport capacity of bus routes. A one-way transit bus route can provide an average of 4 to 11 people per bus for the railway station. Considering a certain level of service reserve, take B as 8 people.

During peak hours, the regular bus departure interval is about 2 ~ 5 minutes. According to Formulas (1) and (2), it can be calculated that, in peak hours, a departure line can provide the maximum transport capacity C_{od} of about 960 people. A one-way route can provide a maximum transport capacity C_o of about 240 people. Similarly, a two-way route can provide a maximum capacity of about 480 people, and the maximum capacity of a starting route is about twice that of a two-way route.

The calculation formula of the total bus transfer capacity C_B provided by the bus lines in the railway station is:

$$C_B=960N_{od}+240N_o+2\times240N'_o \quad (3)$$

Where C_B is the total transport capacity of bus transfer for bus routes; N_{od} is the number of starting routes; N_o is the number of one-way passing stations; N'_o is the number of two-way passing stations.

Under the condition of CB⩾C, the estimated values of N_{od}, N_o, and N'_o can be obtained.

4. Estimation method of land use for bus transfer facilities

4.1 Composition of land for bus transfer facilities

At present, there is no unified standard for the use of land for bus transfer facilities in railway stations in China. In the actual planning projects of the mating land for bus in railway stations, *the Design Code for Urban Public Transport Stations, Farms and Factories* (hereinafter referred to as *the Code for Bus Stations*)[8] in 1988 is usually adopted as the standard. *The Code for Bus Stations* has relevant provisions for the turning lane, stopping pad, waiting corridor, greening, as well as production and living building of the first and last stops: the setting of the first and last stops of buses takes into account the parking of buses at night, so the planning land area of the first and last stops is relatively large. According to the calculation of 90 ~ 100 m^2 of land for each standard bus, a line generally needs to reserve 1 000 ~ 1 200 m^2 of land.

For railway stations located in the built-up areas in downtown, on the one hand, the development of the land surrounding stations is mature and the land is tight, so the difficulty and cost of land acquisition are relatively high; On the other hand, there are a large number of bus routes gathered near railway stations, so the land for rail-bus transfer needs to be reserved centrally. Therefore, bus transfer facilities cannot directly use the above standard, but should try to compress the land use standard on the basis of meeting the transfer demand.

To reduce the land demand for the bus transfer, the railway stations in the built-up areas of the city center generally do not provide nighttime parking, so there is no need to reserve nighttime parking lots except for necessary bus parking spaces. Therefore, the land for bus transfer facilities at rail stations is composed of the following three parts: (1) The land for vehicle operation, including parking space, waiting corridor and turning lane; (2) Production and living construction land, mainly refers to the control rooms of bus routes. According to the investigation of the first and last bus stations in Shanghai, the control room of a starting line covers an area of about 40 m^2; (3) Green land covers about 15% of the total land of the railway station.

4.2 Estimation method for land use of one starting route

Parking space: The departure frequency of general buses is about 5 minutes. Taking into account the parking of standby vehicles, extra vehicles during peak hours and vehicles during work and rest, each departure line should be equipped with 3 parking spaces (i.e. 1 departure space and 2 storage spaces). According to the bus station specification[2], the length of the waiting corridor is the length of three buses plus the vehicle distance (5m)plus 5 meters of safety distance in the front and back, respectively, that is, L=12×3+5+5= 46m. The minimum width of the parking space is W=3m, which is the sum of the bus body width (2.5m), the additional width of the external mirror and the safety distance. The size of the bus is 12m × 2.5m. Waiting corridor: same as parking space, the length of the waiting corridor L=12×3+5+5=46 m. Considering the comfort of getting on and off the bus, the minimum width of the waiting corridor B= 2.5m.

Turning lane: According to *The Traffic Design of Construction Engineering and Parking Garage (Site) Setting Standard*, taking the minimum turning radius (inner diameter) of the bus R=10m, then the width required by the bus to enter and leave the parking space S_a=S_b=R+2.5=12.5 m, and the width of the turning lane is B+W= 5.5m.

The layout of the parking space, waiting corridor and turning lane is shown in the dashed box in Figure 2. The area in the dashed box in the figure is the operation land for vehicles of a starting line.

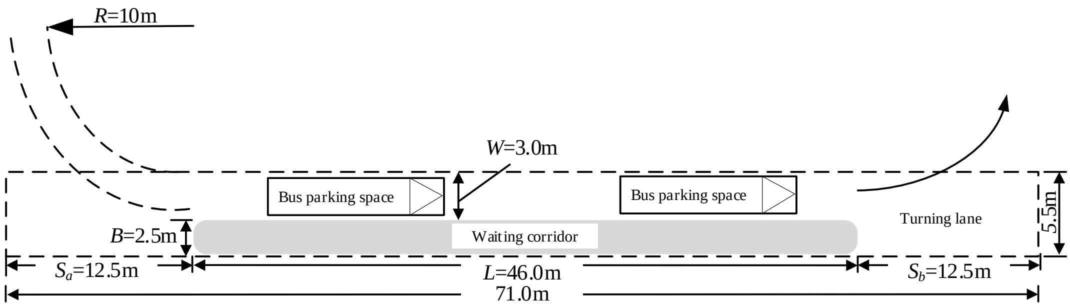

Fig. 2. Map of vehicle operation on one starting line

The bus routes at the railway station are divided into two types: the starting (ending) line and the passing line. The land use needs of the two are different, so their land use area is calculated separately.

The calculation formula of the land area required by one starting line at the railway station is

$$S = \frac{\left(S_a + S_b + L\right) \times \left(B + W\right) + A_c}{85\%} \tag{4}$$

Where S is the land area required by a starting line at the railway station (m^2);$S_a$is the width required by the bus to enter the parking space (m); S_b is the width required by the bus to leave the parking space (m); L is the length of the waiting corridor (m); B is the width of the waiting corridor (m); W is the width of the parking space(m); A_c is the area of the control room (m^2).

According to Formula (4), the minimum land area required by a starting line is S_{min}=513 m^2. In the actual planning process, considering the irregularity of bus transfer plots and the setting of entrances and exits of railway stations, the planned land area S should be slightly larger than S_{min}, and it is recommended to take the minimum planned land area of a starting line as 550 m^2.

4.3 Estimation method for land use of passing routes

When calculating the land area of the passing route, there is no need to consider the setting of production and living buildings, as well as bus storage. According to experience, 3 parking spaces can be shared by at least 3 routes. Therefore, based on the above estimation method, the calculation formula of the land area required by 3 routes with the same platform is

$$S' = \frac{(S_a + S_b + L) \times (B + W)}{85\%} \quad (5)$$

It is calculated that the minimum land area required by the three routes with the same platform is S'_{min}=466 m^2, which is rounded to 500 m^2 in the actual planning and design.

5. Conclusion

The proportion of bus transfer passenger flow in railway stations is high, and the spatial distribution of passenger flow is concentrated in the direction of intersections with railways, and the attraction range of bus transfer is about 6 ~ 8 km. According to the transfer characteristics of bus passenger flow, and taking the rail network as the background, the bus routes near the railway station should be adjusted or merged to roughly overlap with single railway lines for more than 5 km. For the situation that bus routes are partly parallel to or coincide with single railway lines, and bus routes are vertical or intersect with single railway lines, the bus station should be centralized to the railway station entrance and exit as far as possible, so as to facilitate two ways of connection and transfer. Railway stations located in the built-up area of the city center generally do not provide nighttime parking functions due to land shortage. Only necessary bus parking spaces, waiting corridors and control rooms are planned. The minimum planning land of a starting line can be reduced from 1 000 ~ 1 200 m^2stipulated in the code to 550 m^2.

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