Analysis on Optimization of Normal Bus Lines along Urban Rail Transit

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Abstract—Starting with the relations of spatial topological structure between urban rail transit and normal bus lines, this paper expounds the adjustment principles and Strategies of normal bus lines along the line after the completion of urban rail transit from two aspects of station and line. Taking Fuzhou Subway Line 2 as an example, this paper analyzes the characteristics of bus lines with long overlapped sections in the area directly served by the subway stations, and puts forward corresponding suggestions for optimization.

1. Introduction
At present, the planning and construction of urban rail transit lines is the best way to relieve the pressure of passenger flow and improve the travel mode of residents. The main role of urban rail transit in passenger transport is due to its natural advantages such as stronger capacity, faster and more comfortable. Although the volume of normal bus is small, the speed is slow and often delayed, but it has high flexibility and wide coverage, which makes up for the shortage of urban rail transit lines. According to some experience of foreign countries, once an urban rail transit is completed, the traffic counting attracted from the normal bus along the line can reach 60\% -70\%\textsuperscript{[1]}. Therefore, it is necessary to adjust the bus lines along the urban rail to guide passenger flow more reasonably and provide passengers with more time-saving and convenient travel services.

2. Analysis on Spatial Topological Structure
According to the line direction and station location, the relations of spatial topological structure between urban rail transit and normal bus lines can be roughly divided into the following four types: collinear, intersecting, mixed and non-intersecting relations\textsuperscript{[2]}. Details are shown in Tab. 1.
Tab. 1 spatial topological relations between urban rail transit lines and normal bus lines

| Types of Relation | Diagram | Line Characteristics |
|-------------------|---------|----------------------|
| Collinear Relations | ![Diagram](image1) | The direction of the middle section of the normal bus line is consistent with that of the urban rail transit line |
| Middle Collinear Relation | ![Diagram](image2) | The direction of the middle section of the normal bus line is consistent with that of the urban rail transit line |
| Terminal Collinear Relation | ![Diagram](image3) | The direction of normal bus line terminal is consistent with that of urban rail transit |
| Intersecting Relation | ![Diagram](image4) | Only one intersecting point lies between normal bus lines and urban rail transit lines, and there is no collinear section |
| Mixed Relation | ![Diagram](image5) | A collinear relation and intersections lie between normal bus lines and urban rail transit lines. |
| Non-Intersecting Relation | ![Diagram](image6) | No intersecting point and common line section lie between normal bus lines and urban rail transit lines |

3. Analysis on Adjustment of Normal Bus Lines

3.1 Principles of Adjustment

1. For long sections that overlap or parallel with urban rail transit lines with a large number of “collinear relations”, it is necessary to cancel the overlapped sections under the condition of small passenger flow pressure, or the line should be re-planned. In other words, it should be laid outside the direct attraction range of urban rail transit, so as to reduce the waste of traffic resources.

2. In case the traffic counting of the overlapped sections is large, the “common line relation” can be appropriately retained to share the traffic counting pressure. The advantages of the two can be strengthened by combining the advantages of the two, but the length of the overlapped section should be less than 4km[3].

3. In case the line is in “intersecting relation”, the key is to adjust the location of the station, so as to effectively connect the two and reduce the transfer time of travelers.

4. In case the “null relation” are adjusted to “intersecting relation” or “collinear relation”, the bus lines can be extended according to the actual situation of the lines to connect with the urban rail transit stations, and the unrelated lines can be adjusted to the subway connecting lines, so as to enhance the traffic counting distribution function of public transport.

3.2 Strategies of Adjustment

In order to achieve the radiation effect, the normal bus lines should be distributed as “fishbone” outward...
from the urban rail transit stations[^4]. From the structure of the line itself, the adjustment strategy can be divided into two types: adjustment of stations and adjustment of bus line directions.

1) Site Adjustment

As the distribution center of passenger flow, the station plays the role of generating, attracting and transferring passengers. According to the function of the station in the line, the adjustment of the station can be divided into the adjustment of the origin-destination and the adjustment of the intermediate station.

a). Adjustment of Origin-Destination

The volume of passenger flow during peak hours is the standard for judging whether the starting and ending points can be set. The carrying capacity $C$ of the origin-destination of normal buses is as follows:

$$C = \frac{60R \times r}{tk}$$  \hspace{1cm} (1)

In the formula, $R$ is the rated passenger capacity of public transport; $r$ is the full load rate in peak hours; $t$ is the departure interval of 2~5min during peak hours[^5]; $k = \frac{\text{Cross-Sectional Flow around Origin or Destination}}{\text{Cross-Sectional Flow of the Line}}$, the value is generally $1.5 \sim 2.0$.

b). Adjustment of Intermediate Stations

The adjustment of intermediate stations can be divided into: ① optimizing the station location, the main method is to optimize the bus station spacing, and then adjust it in combination with the actual line. According to the relevant provisions of China, the distance between urban line and suburban line is 500 m ~ 800 m, and that of suburban line is 800 m ~ 1000 m[^6]; ② the function of the station is changed to the original and terminal station according to the traffic counting of stations.

2). Adjustment of Bus Line Directions

The analysis of passenger flow direction is the main basis to determine the direction of public transport lines. In addition, in the process of adjustment, the constraints of the line’s own attributes, namely the line length and the non-linear coefficient, should be considered.

The calculation formula of non-linear coefficient is as follows:

$$a = \frac{l}{d}$$  \hspace{1cm} (2)

In the formula: $l$ is the actual length of the line; $d$ is the linear distance between the starting and ending points of the line[^7].

According to The Code for Planning and Design of Urban Road Traffic, $a \leq 1.4$. The length of public transport lines should generally meet the requirements of $5\text{km} \leq L \leq 15\text{km}$[^8]. Too long and tortuous line will increase the operation cost while too short will fail to share the traffic counting, and even bring waste of resources.

4. Analysis on Cases

Fuzhou Subway Line 2, completed and put into operation in 2019, has a total length of about 30.3 km with 22 stations. It meets with Subway Line 1 at Nanmendou Station and undertakes the transportation of main passenger flow from east to west in Fuzhou.

4.1 Overview of Bus Lines along Subway Line 2

The survey results show that there are 110 normal bus lines (excluding night bus lines, subway interchange and special lines) directly served by Subway Line 2 (taking the station as the center and radius of 500m)[^9]. Among them, there are 89 lines with “collinear relation” in spatial topological structure, accounting for 81% of the total lines; 13 lines with “intersecting relation”; 4 lines with “mixed relation”, and the rest with “non-intersecting relation”. This paper takes the normal bus lines with more than 10 stops along overlapped sections as examples. Based on the analysis of the line characteristics, as shown in Tab.2, combined with the road distribution in Fuzhou, corresponding optimization suggestions are put forward.
4.2 Optimization Suggestions
According to the spatial topological structure relation in Tab. 1, combined with the actual line, the following optimization suggestions are put forward.

1). Middle Collinear Relation
There are buses No.150, 32 and 73 in the intermediate collinear line. The specific adjustment suggestions are as follows: the whole line of No.150 is too long and the non-linear coefficient is large, so it is suggested to cut it off from Fuzhou University station to form two lines with the direction basically unchanged. Line 1 is adjusted as the connecting line from the north gate of Minjiang University to Dongyu / Fujian Normal University Station; the starting point of Line 2 is adjusted to the bus University Town terminal, and the adjusted line length is 7.5km and 16.6km, and the non-linear coefficient is 1.29 and 1.95 respectively. Due to the force majeure of the actual direction of Line 2, it is difficult to adjust the non-linear coefficient to within the standard (1.4), but it should be reduced as far as possible; the 32 overlapped sections are in the Fuzhou Higher Education Mega Center, and the average passenger flow is large, and it is the main line to the Juyuanzhou Bridge, so it is not adjusted; the whole line and overlapped line of line 73 are long, and the traffic counting of overlapped section is small, so it is suggested to cancel some overlapped lines The starting point is adjusted to Liyuan Bus Terminal to form the terminal common line relation and enhance its pick-up function, while other stations and lines remain unchanged.

2). Collinear Relation
There are 115, 69 and 7 lines in the terminal. The specific adjustment suggestions are as follows: the non-linear coefficient of line 115 is larger and the overlapped section is longer. Considering the less passenger flow of Fuma Rd., it is suggested to cancel the overlapped line and adjust it to the feeder line with Ziyang Subway Station as the terminal point; there are many bus stops involved in the overlapped section of line 69, and the average station spacing is 354m, It is suggested to cancel the stops at Gutian-Liuyi Crossing Station, Damingcheng Station and Fujian Revolutionary History Memorial Hall Station; the degree of line 7 overlapped with the subway line is as high as 51%, which forms a strong competitive relation with Line 2. It is suggested that part of the overlapped lines should be cancelled and adjusted to continue along Guohuo Rd. E. – Yuanyang Rd. – Dongsanhuan Rd. – Fuma Rd. from An’dan Bus Station.

Tab.2 characteristics of lines with 10 or more bus stops in overlapped lines

| Bus Lines | No.150 | No.32 | No.115 | No.107 | No.69 | No.7 | No.73 |
|-----------|--------|-------|--------|--------|------|------|-------|
| Line Length /km | 25.5 | 23.9 | 14.2 | 15.8 | 13 | 14.5 | 25.9 |
| Linear Distance/km | 10.9 | 18.1 | 7.9 | 11.8 | 9.1 | 11 | 18.8 |
| Non-Linear Coefficient | 2.34 | 1.32 | 1.8 | 1.34 | 1.43 | 1.32 | 1.38 |
| Length of Overlapped Line /km | 4.4 | 5.9 | 5.4 | 6.4 | 4.6 | 7.4 | 8.3 |
| Degree of Overlap | 0.17 | 0.25 | 0.38 | 0.41 | 0.35 | 0.51 | 0.32 |
| Overlapped Sections | Guobin Ave. Qishan Ave. | Guobin Ave. Qishan Ave. | Fuma Rd. | Fuma Rd. | Gutian Rd. Fuma Rd. | Gutian Rd. Fuma Rd. | Gutian Rd. Fuma Rd. |
| Number of Bus Stops along Overlapped Sections | 10 | 11 | 10 | 13 | 13 | 13 | 13 |
After adjustment, the degree of the overlapped lines is 12.5%, and the non-linear coefficient is 1.18.

3). Mixed Relation

The line of bus No.107 is mixed, which include middle and terminal collinear relations. Due to the overlapped section of the line of No.107 is long and the middle collinear section is within the area directly served by the subway, it forms a competitive relation with subway. It is suggested to adjust the line direction and enter Lianyang Rd.W.-Lianyang Rd.-Fuma Rd.-Gushan Bus Terminal from Wuliting Station to reduce the traffic counting competition with Line 2.

5. Conclusion

Based on the investigation and analysis of the lines in the area directly served by Fuzhou Subway Line 2, according to relevant adjustment principles and strategies, combined with the characteristics of the line, this paper puts forward suggestions for adjustment of the bus lines with long repeat sections and many stations along the urban rail transit. However, many factors need to be taken into account for the adjustment of normal bus lines along the subway, which usually involves the adjustment of the whole bus network. Thus, the suggestions for adjustment put forward in this paper still need to be improved.

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