Optimization of Transfer Layout and Organization on Urban Rail Transit
— A Case Study on Split Scheme of Beijing Rail Transit Line 13

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Abstract—Based on the practical case "the Consultation on Split Scheme of Beijing Rail Transit Line 13", this paper collects and forecasts the passenger flow information, to combine the situation of the line with the surrounding land use, to probe into those possible problems of the existing split scheme deeply. By adopting digital construction technology, three sets of transfer layout optimization schemes are studied and designed, in order to realize the seamless connection between 13A Line and 13B Line after split. Then, this paper is supposed to establish the index evaluation system, and the satisfactory optimization scheme is obtained by the comprehensive comparison and selection from the aspects of convenience for passengers, feasibility of scheme implementation and so on. AnyLogic software is used to build a simulation model of human-vehicle interaction, which realizes the effect display and dynamic index acquisition. And the optimization effect is analyzed from the perspective of transfer platform security.

1. INTRODUCTION

Beijing Rail Transit Line 13 is an important way for the residents in the northern part to travel. However, in recent years, the passenger flow along the line has increased, and the demand of Line13 has far exceeded the capacity.

In order to improve the travel conditions of residents in these areas, on November 22, 2018, Beijing Municipal Commission of Planning and Natural Resources published "The Splitting Project Scheme of Beijing Rail Transit Line 13", which divided the existing Line 13 into two "X" lines located in the north of the city, as shown in Fig. 1.

Figure 1. Schematic Diagram of Line 13 Split Project.

Based on paying attention to Beijing rail transit planning and construction for a long time, and the study of existing easy interchange mode at home and abroad [1], this paper hopes to do further in-depth
study of the problems with the existing scheme and puts forward the better suggestion and the adjustment scheme. Therefore, it can bring into play the greater social benefits of existing scheme. At the same time, this work can lay the foundation for the integration of network and comprehensive transportation junction.

2. ANALYSIS OF PROBLEMS IN THE EXISTING SPLIT SCHEME

2.1. Basic Information of Transfer Station

After a preliminary analysis of the existing scheme, this paper mainly selects four major transfer stations, namely Xinlongze Station, Longze Station, Xierqi Station and Qinghe Station, as field research objects.

Xinlongze Station is a double-line transfer station between Line 13A and Line 13B in the split scheme, and it is planned to set up a transfer station with two sets of four lines. From the satellite map, there is a large vacant land between the west of Beijing-Tibet Expressway and the east of Zhongguancun Forest Park, which can be fully used for the construction of the transfer platform. This is also the fundamental reason why the existing scheme chooses to build a new station here for the transfer of Line 13A and Line 13B.

Longze Station is an existing station of Line 13, which is located between Xinlongze Station and Huilongguan Station and belongs to the elevated station. According to the satellite map, the two sides of Longze Station are mainly roads and green fields, with a width of about 130 meters. The space conditions are relatively sufficient. In the existing split scheme, Longze Station is proposed to move 140 meters to the east, and add the two elevated overpass entrances in the south of the railway, so the residents in the south can enter the station directly on the bridge with the travel convenience greatly improving.

Xierqi Station is the transfer station of Line 13 and Changping Line. It is located between Xinlongze Station and Qinghe Station. The station has two above-ground layers and a semi-underground layer. The actual engineering conditions are as follows:

- The ground floor of Xierqi Station is the platform of Line 13, and there is not only Beijing-Baotou Railway, but also new Beijing-Zhangjiakou High-speed Railway which is under construction in the east. Instead of building a subgrade on the ground, the double line has been bridged. The viaduct occupies most of the space on the east side, making it difficult to extend the line.
- The west side of Xierqi Station is adjacent to Shangdi East Road and G7 elevated Beijing-Xinjiang Expressway, so there is little room for expansion, which causes great difficulties for the construction of the line.
- The current Xierqi Station is the new station on the north side shown in the red box of Fig. 2, while the old station is abandoned and undismantled on the south side shown in the yellow box, which may affect the laying of the line to some extent.

Qinghe Station is a comprehensive hub connecting a variety of transportation routes and is still under construction in the first phase. It mainly consists of two floors above ground and two underground floors. Among them, the ground floor is the platform floor, including the state railway entrance exhibition hall, the state railway platform and the newly built subway Line 13 platform; the second floor is the south extension of Changping Line and the platform floor of No.19 Branch Line.
2.2. Passenger Flow Data Investigation and Data Processing

2.2.1. Investigation Method
In this paper, the three periods of morning peak (7:20-8:20), noon peak (11:20-12:20) and evening peak (18:00-19:00) are selected to investigate the passenger flow data of the existing Line 13. Eight researchers were divided into two groups, which were respectively responsible for recording the passenger on-off data of 1 and 3 carriages in a subway, and then calculating the spatial distribution characteristics of passenger flow and passenger flow characteristics of sections in different periods.

2.2.2. The Data Processing
In the process of data processing, due to the limited number of respondents, the complete data of a train cannot be accurately obtained. In order to reduce the calculation error, it is assumed that the number of passengers in the train is 0 at Xizhimen Station, and the data is adjusted to ensure that the total number of people on board and the total number of people off are equal. At the same time, assuming the passenger flow of the whole train between the two stations can be calculated as:

\[ X_{ij} = 2S_1 + 2S_3 + \frac{S_1 + S_3}{2} \times 2 = 2S_1 + 2S_3 + (S_1 + S_3) = 3S_1 + 3S_3 \]

\[ (i = 1,2,...,15; j = 2,3,...,16) \]

\[ X_{ij} \quad \text{Passenger flow between Station i and Station j}; \quad S_1 \quad \text{Passenger flow at all times in the first carriage}; \quad S_3 \quad \text{Passenger flow at all times in the third carriage}. \]

In addition, because there are more stations under construction and the basic information is imperfect, in this paper, by comparing the known information (Such as property of surrounding land, whether the station is a transfer station for other lines, the station location on this line, etc.), similar stations are found. Based on the actual passenger flow survey data of the existing stations, the least square method is adopted to predict the reasonable passenger flow.

Calculate separately and obtain the hourly average passenger flow and section passenger flow of Line 13A and Line 13B.

2.3. Possible Problems with Split Scheme

2.3.1. the Passenger Pressure of Transfer Station is heavy during Peak Hours.
Xinlongze Station in the existing planning scheme is the transfer station which can realize the same station transfer in four directions: "B15 - A01", "A01 - B15", "A18 - B01", "B01 - A18". However, for the transfer direction from "A18" to "A01", due to the high full self-load factor from "A11 - A17" on Line 13A, a large number of passengers cannot be transported from "B15" to "A01". There will be a large backlog of passengers in a short time and this will bring some passenger flow pressure to the platform of Xinlongze Station.

2.3.2. Transfer convenience consideration in "Corner Passenger Flow" is insufficient.
Although the existing planning scheme has realized the transfer in the above four directions in the same station, it has not paid enough attention to the areas with great transfer demand. For example, in directions like "A01 - B01" or "B01 - A01", passengers mainly need to transfer through Xinlongze Station from Line 13A/B to Line 13B/A and there is a certain detour distance, as shown in Fig. 4 at left.

In addition, the existing scheme also does not consider the convenience of transfer from "B01" to "Changping Line", as shown in Figure 4 at right. In this path, passengers not only need to detour, but also go after two transfers.

2.3.3. Multi-line fusion degree in Qinghe Station is not sufficient.
Qinghe Station is integrated into Line 13A, which will improve the accessibility to other areas for the passengers in the northern part of Haidian and Changping. However, based on the current Line 13A and Line 13B, if the passengers in "Back Mountain Area of Haidian" and "Malianwa Area" go to the direction of Qinghe, their way out is not smooth. They need to arrive at Xinlongze Station first, then transfer by going up and down the building to the train of Line 13A, and finally arrive at Qinghe Station. This increases the transfer time. Therefore, in a comprehensive view, the current integration scheme of Qinghe Station, Changping Line, and high-speed line needs to be enhanced.

3. TRANSFER LAYOUT OPTIMIZATION SCHEME DESIGN

3.1. Based on the Basic Design Concept of Double Station Transfer at the Same Platform
Some researchers [2] [3] defined and analyzed the common single-station and double-station transfer between stations and platforms in urban rail transit. They believe that the "zero" transfer demand of all passengers can be met by a double-station transfer at the same platform and in the case of investment permit and little impact of construction site on urban traffic a double-station transfer at the same platform should be chosen to use as far as possible. In this paper, the design can also improve the transfer convenience of "Corner Passenger Flow".

Considering the feasibility of the optimization scheme, this paper suggests that based on the existing station (Xinlongze Station), a new station transferred at the same platform should be added in a relatively close area. On the one hand, considering the possibility of setting the adjacent stations, option 1 and option 2 are proposed to realize a double-station transfer at the same platform to the east and the south respectively. On the other hand, considering the connectivity of the whole road network and the degree of multi-line integration, option 3 is proposed.
3.2. Determination of Optimization Scheme

3.2.1. Option 1 and Option 2
On the basis of the existing scheme, Option 1 adjusts the position of Line 13A as shown on the right in Figure 5, merges Longze Station (B05) and Yuzhi East Road Station (A12), and sets the transfer platform at Longze Station (B05) after the adjustment. Option 2 adjusts the position of Line 13B as shown on the left in Fig. 5, merges Shangdi West Rad Station (B03) into Xierqi Station (A10), realizes the convergence of three lines including Changping Line, and sets the transfer platform at the same station here.

![Figure 5. Adjustment Diagram of Option 1 and Option 2.](image)

The combined Longze Station (B05&A12) in Option 1 can realize transfer to the following directions in the same station: the passenger flow from Dongzhimen Station on Line 13B to the direction of Tiantongyuan Station on Line 13A; the passenger flow from Xizhimen Station on Line 13A to the direction of Shangdi Station on Line 13B. And the Xinlongze Station (A11&B04) in the current scheme can realize transfer to the following directions in the same station: the passenger flow from Dongzhimen Station on Line 13B to the direction of Xizhimen Station on Line 13A; the passenger flow from Tiantongyuan Station on Line 13A to the direction of Shangdi Station on Line 13B.

![Figure 6. Design Drawing of Option 1 and Option 2.](image)

The combined Xierqi Station (A10&B03) in Option 2 and the existing Xinlongze Station (A11&B04) can achieve the different transfer direction in the same station and it is as above. In addition, Xierqi Station is also responsible for the transfer between Line 16 and Line 13A as well as Changping Line and Line 13.

The route layout between stations and basic structure of the station in two options are shown in Fig. 6.

The technical rationality to Option 1 is analyzed as follows: a) Double transfer stations are set up so as to reduce the passenger flow pressure and safety risk of the station. b) The merging of the two stations can reduce the project cost and construction cost. c) It is of little help to the connection between Changping Line, and Line 13 A and B. d) This option fails to make full use of Qinghe High-speed Railway Station which has sufficient space conditions.
The technical rationality of Option 2 is analyzed as follows: a) It realizes three-line convergence at Xierqi Station. b) It can improve the connectivity of the five lines (Changping Line, Line 13 A, Line 13 B, Line 16 and Line 19), and improve the service capacity of the road network. c) This option still fails to make full use of Qinghe Station which has sufficient space conditions.

3.2.2. Option 3

On the basis of the existing scheme, Line 13B is adjusted as shown in Fig. 7, that is, Line 13B is parallel to Line 13A after leaving Xinlongze Station (A11). Then enters Qinghe Station (A09) via Xierqi Station (A10). It will achieve four-line convergence with Changping Line, Beijing-Zhangjiakou High-speed Railway, Line 13 A and B, and set the transfer station here.

The transfer directions which can be realized of the same station in Qinghe Station (A09) and Xinlongze Station (A11 & B04) are the same as above.

The layout of the line among the three stations and the basic structure of the station are shown in Fig. 8. On the one hand, according to the basic structure of Qinghe Station construction planning which is mentioned above, the platform on the ground floor is horizontally extended, and the transfer platform to Line 13 A and B will be set up. On the other hand, considering the engineering conditions of Xierqi Station, Line 13A is set on the ground floor (the existing Line 13A). Line 13B is not set here and it will be directly elevated through in order to reduce the passenger flow pressure during the peak hour of Xierqi Station.

![Figure 7. Adjustment Diagram of Option 3.](image)

From the property of surrounding land around B03 station, it can be known that the passenger flow here is not large. If B03 can be set, it will be considered setting up on the appropriate position between the adjusted B02-A09. The demand for passenger flow in this area will be significantly greater than the current scheme site selection. Or cancel station B03 as shown in this adjustment scheme.

![Figure 8. Design Drawing of Option 3.](image)

The technical rationality of Option 3 is analyzed as follows: a) The four-line convergence of Changping Line, Line 13A, Line 13B and Beijing-Zhangjiakou High-speed Railway is realized at Qinghe Station, which greatly facilitates the travel of passengers. b) It can improve the connectivity of Changping Line, Line 13 A, Line 13 B, Line 16, Line 19 and Beijing-Zhangjiakou High-speed Railway, and improve the network service capacity. c) If Qinghe Integrated Hub is joined up, it is conducive to making full use of the space and it is easy to relieve the pressure of passenger flow during peak periods.
4. OPTIMIZATION SCHEME COMPARISON AND OPTIMIZATION EFFECT ANALYSIS

4.1. The Establishment of Comprehensive Index System

The establishment of the comprehensive index system includes two sub-systems: the index comparison which considers the comparison between the optimization schemes, and the index evaluation which considers the optimization effect analysis of the optimal schemes.

Among them the sub-system of index ratio selection includes two aspects: a) Passenger travel convenience index: Optional passenger transfer direction quantity, the number of transfer directions for the same station, average number of transfers for 4 lines passengers, average transfer time of 4 lines passengers.  b) Feasibility index of program implementation: Space condition and engineering technical difficulty.

The sub-system of index evaluation mainly includes one aspect, that is, the safety index of transfer platform: The number of people gathered at each station platform in real time, passenger flow density in bottleneck area and sectional passenger flow.

4.2. Optimization Scheme Index Selection

4.2.1. The index of passenger travel convenience is compared:

Quantitative analysis is mainly used to obtain the index of passenger travel convenience. For convenience, we assume that Line 13A is a, Line 13B is b, Changping Line is c, and Beijing-Zhangjiakou High-speed Railway is d.

4.2.1.1. The number of transfer directions:

The sum of the number of transfer directions between the two lines that passengers can choose from the four main transfer stations is defined as the number of transfer directions.

| Station Name | Longze Station | Xinlongze Station | Xierqi Station | Qinghe Station | Count |
|--------------|----------------|-------------------|----------------|---------------|-------|
| Existing     | ----           | a ↔ b             | a ↔ c          | a ↔ c ↔ d     | 5     |
| Option 1     | a ↔ b          | a ↔ b             | a ↔ b          | a ↔ c ↔ d     | 6     |
| Option 2     | a ↔ b          | a ↔ b ↔ c         | a ↔ c ↔ d     |               | 7     |
| Option 3     | a ↔ b          | a ↔ b ↔ c         | a ↔ b ↔ c ↔ d |               | 10    |

4.2.1.2. The number of transfer directions for the same station: The number of transfer directions can be solved by setting transfer directions for the same station. Obviously, in the existing scheme, the transfer directions in the single station can only solve 4 directions, while in the optimized scheme, the transfer directions in the double stations can solve 8 directions.

4.2.1.3. Average transfer times of passengers of 4 lines: The average number of two-two (pair) transfers among line a, b, c and d is defined as the average number of transfers for 4 lines passengers.

| Unit: times | a ↔ b | a ↔ c | a ↔ d | b ↔ c | b ↔ d | c ↔ d | Average |
|-------------|-------|-------|-------|-------|-------|-------|---------|
| Existing    | 1     | 1     | 1     | 2     | 2     | 1     | 1.3     |
| Option 1    | 1     | 1     | 1     | 2     | 2     | 1     | 1.3     |
| Option 2    | 1     | 1     | 1     | 1     | 2     | 1     | 1.2     |
| Option 3    | 1     | 1     | 1     | 1     | 1     | 1     | 1       |
4.2.1.4. Average transfer time of passengers of 4 lines: The average time of two-two (pair) transfer among line a, b, c and d is defined as the average time of transfers for 4 lines passengers. According to the research on the travel time law of subway channel transfer passengers [4], this paper sets the transfer time of all channels transfer passengers to be about 5min, and the transfer time of passengers with the same platform is about 0.2min.

| TABLE III. AVERAGE TRANSFER TIME INDEX OF PASSENGERS AMONG 4 LINES |
|---------------------------------------------------------------|
|                  | Unit: minute |
|                  | a ↔ b | a ↔ c | a ↔ d | b ↔ c | b ↔ d | c ↔ d | Average |
| Existing         | 0.2   | 5     | 5     | 10    | 10    | 5     | 5.87    |
| Option 1         | 0.2   | 5     | 5     | 10    | 10    | 5     | 5.87    |
| Option 2         | 0.2   | 5     | 5     | 5     | 10    | 5     | 5.03    |
| Option 3         | 0.2   | 5     | 5     | 5     | 5     | 5     | 4.2     |

4.2.2. Comparison and Selection of Feasibility Index for Program Implementation.

4.2.2.1. Station amalgamation conditions: In the first two options, the straight-line distances between the two merged stations are 1.43km and 700m respectively, which means the two stations are relatively close and have the merger conditions. Then in Option3, the distance between Qinghe Station and South Street of Software Park is about 2.5km, which is in line with the general subway station spacing.

4.2.2.2. Line height difference condition of adjacent stations: In the three options, the maximum height difference that needs to be realized is 3 layers, 4 layers and 4 layers respectively. As we know, China's "Subway Design Code" stipulates that the slope of the main line for the subway is generally no more than 30%. According to the slope calculated by the distance between adjacent stations, the three options can all meet the design requirements.

4.2.3. Summary.

Obviously, Option 3 has an overwhelming advantage in terms of the index of passenger travel convenience, and there are almost no difficulties in the implementation of the plan, so it is the optimal transfer layout plan that can be recommended in practice.

4.3. Optimization Effect Analysis Based on AnyLogic Simulation

The transfer platform layer model of the same station is built and the stairs and the train waiting area are set up. As for the added subway train model, it is known that Line 13A uses 8 marshalling trains, while Line 13B uses 6 marshalling trains. And the departure interval and the stopping time should be mainly set up according to relevant information [5]. For the added pedestrian model, this paper divides pedestrians into three settings according to different walking paths, including: ① Passengers who walk into a station to board a train or go through the channel to transfer on a train; ② Passengers who get off the train and go out the station or go through the channel to transfer; ③ Passengers who will transfer at the same platform.

In AnyLogic software, the information of passenger flow data obtained above is input by setting different pedestrian flow speed. Set up the interaction between pedestrian flow and track flow, and collect the real-time gathering passenger number at the platform, passenger flow density in bottleneck areas (e.g. stairs, train waiting areas, etc.), cross section passenger flow and other real-time dynamic data.

Finally, the operation effect of the simulation model are as follows: First, the pedestrian thermal diagram effect is added to the two-dimensional operation diagram, and the number of people gathered at the platform is displayed in the upper left corner in real time [6], as shown in Fig. 9; Second, add the passenger character model and the side-view camera to the three-dimensional operation diagram, as shown in Fig. 10.
Figure 9. Simulation Model Two-dimensional Operation Effect.

Figure 10. Simulation Model Three-dimensional Running Effect.

Figure 11. Operation Results of Evaluation Indexes.

The operation results of the evaluation indicators are shown in Figure 11. The data indicators of the platform above are shown on the left, and those of the platform below are shown on the right.

After calculation, the average results in Table 4 are obtained.

The density of passenger flow is inversely proportional to the walk speed [7] [8]. When the passenger flow density reaches 2 persons /m^2, passenger speed is very slow (< 0.4 m/s). Travel experience is unwell. When the passenger flow density is lower than 0.8 /m^2, passengers can travel freely and are almost unaffected by crowding.

In the comprehensive optimization scheme, the passenger density which is in the bottleneck area is higher than 0.8 人/m^2. Other areas are even lower than this value, which has obviously alleviated the passenger flow pressure of the platform and improved the travel experience of passengers.

| Evaluation Index Calculation Results |
|-------------------------------------|
| Platform attendances | Passenger flow density in bottleneck area | Subhead Section passenger flow in bottleneck area |
| Optimization | 528 | 0.83 | 2678 |

5. CONCLUSION
Through the comparison and selection of different optimization schemes, the final scheme can get the improvement of the following indicators compared with the existing scheme: The average transfer time among the four lines has been reduced by about 28.4%. The average number of transfers between the four lines has also decreased from 1.3 to 1 (i.e. 23.1%). The number of transfer directions in the same platform increased from 4 to 8. The number of optional transfer directions has also been increased from
The probability of real-time aggregation during peak hours is reduced by more than 30%. The free travel of passengers can be realized. To sum up, it can basically solve the problems that may exist in the original scheme and greatly improve the travel experience of passengers; at the same time, it can give full play to the transportation capacity of the line network and reduce the pressure of transportation organization.

In addition, if the transportation organization measures of "Y" type train routing can be supplemented on the basis of the transfer layout optimization scheme, the problems of uneven passenger flow distribution among the four bifurcated sidings in the "X" type separation scheme, as well as the possible problems of too much platform load and subsequent capacity waste in the same platform transfer design can be effectively solved.

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