Simulation Analysis of the Exit Capacity of Depot of Urban Rail Transit

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Abstract—A large number of subway trains depart from the depot before the morning rush hour, so the exit capacity of depot is insufficient. Using Anylogic software as the simulation platform, the paper has carried out an in-depth study on the exit capacity of depot from the perspectives of the access line and the main line, analyzed the impact of access lines capacity on exit capacity of depot under different conditions; researched the impact of different main line occupancy conditions caused by different traffic densities on exit capacity of depot. Taking the existing exit capacity of depot of Taipinghu Depot as an example, corresponding optimization scheme is put forward, and the effectiveness is verified by building a simulation model.

1. INTRODUCTION

In the case of reasonable vehicle types, signal equipments, and transportation organization methods, the train exit capacity of depot means that the maximum number of urban rail transit trains within a unit time, when the train starts from the parking line of operation depot, passes through the throat area, the access line, the transition track, finally arrives the main line.

With the improvement of the urban rail transit network, urban rail transit based on subways has become an important mode of transportation for citizens in large and medium-sized cities. Due to the commuting attribute of subway, the characteristic of time distribution about subway passenger flow in a day is obvious, and the number of trains on the line during the morning and evening rush hours is much more than that during the peak period. In order to meet the travel needs of passengers and reduce capacity waste, a large number of trains will inevitably depart the depot before the morning and evening rush hours, which lead to a situation of insufficient train capacity.

The exit capacity of depot should be consistent with the operation capacity and train's operational interval on main line\cite{1}. At present, the research on the exit capacity of depot mainly adopts the analytical calculation method, the exit capacity of depot is obtained by analyzing and calculating the time required for each process of the train exiting the depot \cite{2}, \cite{3}. At the same time, the existing studies mostly focus on the perspective of the depot, and there are few studies about train exiting depot which influencing by operation capacity on main line \cite{4}.

In order to alleviate the contradiction between the exit capacity of depot and operation capacity on main line\cite{5}, it is necessary to sort out the operation methods and procedures of exiting depot. On this basis, this article discusses the influence of the access line on exit capacity of depot, forms the conclusion about the exit capacity of depot including the "input" and "output", provides a basis for...
further improving the train exit capacity of depot, increasing the operation service level of line and optimizing the operation diagram.

2. TYPES OF OPERATION ABOUT EXITING DEPOT

As shown in Fig. 1, the trains operation of exiting depot can be roughly divided into four stages: operation in the operation depot; operation in the throat area; operation in the access line; operation from the access line to the main line via the transition track.

The exiting depot ways of urban rail transit trains mainly include the trains route way in single time and the trains route way in many times. The trains route way in single time means that the trains’ entry from the operation depot to the transition track is completed at one time. The trains route way in many times means that the train first operates to the single departure signal by shunting, and then route is processed, after the signal is opened, the train completes the exit operation. After the preceding train passes signal, subsequent trains can be adjusted to the signal and wait to enter the transition track [6].

![Figure 1. Schematic diagram of exiting depot](image1)

When the train adopts the trains route way in single time to exit depot, the train operates directly to the access line after the exit signal is opened. Subsequent trains can’t enter the access line until the preceding train is completely out of the access line. The tracking interval of the two trains is the time from leaving the operation depot to being out of the access line, as shown in Fig. 2. When the train adopts the trains route way in many times, subsequent trains are allowed to be shunted to the single departure signal in advance, as shown in Fig. 3, the tracking interval is greatly reduced.

![Figure 2. Schematic diagram of the trains route way in single time](image2)

When the access line is arranged, it is often used in double lines and double directions. Therefore, it can be divided into exit from the right segment of the access line, exit from the left segment of the access line, and exit from the double lines according to the different uses of the access line [7]. As shown in Fig. 4, it is a common access line layout which is connect to terminal track of main line, it can be used in double lines and double directions.

![Figure 4. Schematic diagram of depot layout](image4)
3. SIMULATION ANALYSIS ABOUT EXIT CAPACITY OF DEPOT
Taking the existing layout of depot as a reference, a simulation diagram of the depot is formed, as shown in Fig. 5. The stub-end design, where the access line is connected to the terminal track of the main line in a three-dimensional manner, is a form that is currently used more in actual routes. The simulation areas mainly include the operation depot, the throat area, the access line, the main line, and the station.

![Diagram showing depot layout](image)

Figure 5. Schematic diagram of depot simulation

The red frame area on the right side of the picture is the operation depot, which is responsible for the parking, trains inspection, and trains cleaning. Since this study does not consider depot operation such as bi-weekly/March inspections that take long time and have little impact on the exit capacity of depot, the maintenance depot, dispatch depot and other production depots are ignored, and the operation depot which is closely related to the operation of exiting depot is emphasized. The blue frame area on the left is an intermediate station of the line, which is the station closest to the junction of the access line and the main line, and outbound trains will stop at the station. The track marked green is a transition track, where trains will stop to switch the operation mode.

3.1 Analysis of Access Line Capacity
The analysis of the access line capacity is an important part of the analysis of the exit capacity of depot. In this subsection, other capacities in the depot are not considered, such as the impact of the storage line and the maintenance capacity on exiting depot, and the impact of trains operating on the main line on the exit capacity of depot, this part only focuses on the impact of the access line on the exit capacity of depot.

In the case of the above-mentioned depot layout, the model of exiting depot is constructed by adopting the trains route in many times and exiting depot from double access lines. After the trains route of exiting depot is arranged and the single departure signal is opened, the train will exit the operation depot at a speed not higher than 5km/h, pass through the throat area at a speed not higher than 17km/h, and select any free exit line to exit, complete the conversion of trains operation mode on the transition track, and further wait for entering the main line after the route signal is opened.

Through the adjustment of the interval between two consecutive trains when the trains are arranged for route from the operation depot (After that, it is called train departure interval), the step length is set to 5s each time. In the case of safe and reasonable operation, the maximum number of exiting depot trains completed in the 1 hour simulation period is made, and the data are recorded.

According to the above rules, the simulation is carried out and this experiment is defined as simulation 1. The maximum trains exit capacity of depot per unit time (one hour, the same below) is 27. At this time, the train departure interval is 125s. Partial data are shown in the table 1.

| Number | Time of exiting operation depot (min) | Time of exiting depot(min) | Operation time in depot(min) |
|--------|--------------------------------------|---------------------------|----------------------------|
| 1      | 0.00                                 | 4.81                      | 4.81                       |
| 2      | 2.08                                 | 6.88                      | 4.80                       |
| 3      | 4.17                                 | 8.98                      | 4.81                       |
| 4      | 6.25                                 | 11.05                     | 4.80                       |

TABLE 1. PARTIAL DATA OF EXITING DEPOT INFORMATION IN SIMULATION 1
According to the simulation results, it can be seen that the main factor which affects the exit capacity of depot is the minimum interval between adjacent trains. The minimum interval between adjacent trains is related to the train block zones. The shorter the train block zones divide, the more trains can exit the depot on the access line at the same time. The shorter the minimum interval between adjacent trains is, the greater the exit capacity of depot will be.

### 3.2 The Impact of Train’s Interval ofExiting Depot

When the train adopts the trains route way in many times, it can reduce the length of a single route, increase the number of route arrangements, and decrease the interval of exiting depot. The simulation process of designing with the trains route way in many times is defined as simulation 2. The single departure signal is marked red in Fig. 6. After the trains route way in many times is used to exit the depot, an access line can be allowed to be occupied by two trains at the same time, thereby achieving the purpose of increasing exit capacity of depot.

![Figure 6. Schematic diagram of route division](image)

In the simulation 2, the interval of exiting operation depot is adjusted, and the step length is set to 5s each time, leading the maximum exit capacity of depot per unit time (one hour) is 30. At this time, the interval of exiting operation depot is 105s. It can be seen that adopting the trains route in many times can improve the exit capacity of depot to a certain extent.

Under the condition of a fixed interval of exiting operation depot, since the train needs to switch the mode on the transition track and wait for the main line track to be free before entering, the train can leave the depot through two access lines, but the train can only enter one main line in this layout mode, that is, it needs to go through a process of "merging". As shown in Fig. 7, when the train operates on the access line, the operation interval is S₁, after entering the main line, the operation interval is S₂, and S₂ is significantly smaller than S₁. However, due to the limitation of the passing capacity of the subway station, in this system, the passing capacity of the main line is less than twice as much as the exit capacity of depot, as a result, the passing capacity of the main line limits the exit capacity of depot.

|   |    |    |    |
|---|----|----|----|
| 5 | 8.33 | 13.16 | 4.83 |
| 6 | 10.42 | 15.23 | 4.82 |
| 7 | 12.50 | 17.34 | 4.84 |
| 8 | 14.58 | 19.41 | 4.83 |
| 9 | 16.66 | 21.48 | 4.81 |
| 10 | 18.75 | 23.55 | 4.80 |
| ... | ... | ... | ... |
| 23 | 45.83 | 50.67 | 4.85 |
| 24 | 47.91 | 52.75 | 4.84 |
| 25 | 49.99 | 54.81 | 4.82 |
| 26 | 52.08 | 56.88 | 4.81 |
| 27 | 54.16 | 58.98 | 4.82 |
3.3 The Impact of Single Access Line Operation

Under the premise that only one access line can be used to complete the operation, the simulation process for designing with the trains route in single time is defined as simulation 3, and the simulation process for designing with the trains route in many times is defined as simulation 4.

In simulation 3 and simulation 4, the interval of exiting operation depot is adjusted, and the step length is set to 5s each time. Meanwhile, the simulation results that compare with simulation 1 and simulation 2 are shown in Table 2.

| Number   | Operation modes                                      | Interval of exiting depot (s) | Operation time of exiting depot (s) | Capacity of exiting depot (train/h) |
|----------|-----------------------------------------------------|------------------------------|-------------------------------------|-----------------------------------|
| Simulation 1 | Double access lines, trains route in single time     | 125                          | 289                                 | 27                               |
| Simulation 2 | Double access lines, trains route in many times      | 105                          | 414                                 | 30                               |
| Simulation 3 | Single access line, trains route in single time      | 195                          | 289                                 | 17                               |
| Simulation 4 | Single access line, trains route in many times       | 120                          | 292                                 | 28                               |

By comparing the data obtained in Simulation 1 and Simulation 3, it can be seen that the use of double access lines operation has greatly reduced the interval of exiting depot and improved the exit capacity of depot by nearly 60%. When the main line capacity is sufficient, the double access lines operation way to exit depot can greatly increase the exit capacity of depot.

Compared with the simulation 2, in simulation 4, under the condition of reducing one access line, the exit capacity of depot is only reduced by two, which further proves that the passing capacity of the main line in simulation 2 limits the exit capacity of depot. Because trains in simulation 4 adopt the trains route way in many times, the exit capacity of depot under the condition of single access line is one more than simulation 1 that uses double access lines. Divided the trains route way in single time into many times can greatly improve the exit capacity of depot.

It can be seen from simulation 3 and simulation 4, the depot still retains a certain amount of exit capacity of depot under the condition of single access line operation. Without the need to increase the
number of trains on the line in a short time, single access line operation can meet actual operation demands.

3.4 The Impact of Main Line Operational Vehicles

Except for the trains listed in the first few sections of the day, when the train leaves the depot, there are trains on the main line that will operate normally. When these trains pass through the depot near the access line junction point, the track will be occupied, which limits the time of exiting the depot.

Under the condition of three traffic densities with average operational interval of 10 minutes, 7 minutes, and 5 minutes on the main line, the simulation design are carried out through the route operation of double access lines, which are defined as simulation 5, simulation 6 and simulation 7 respectively. The simulation results are shown in Table 3 for the influence of the main line operational vehicles on the exit capacity of depot.

| Number    | Operation interval on main line (min) | Interval of exiting depot (s) | Capacity of exiting depot (trains/h) |
|-----------|--------------------------------------|-----------------------------|-------------------------------------|
| Simulation 5 | 10                                   | 150                         | 23                                  |
| Simulation 6 | 7                                    | 205                         | 17                                  |
| Simulation 7 | 5                                    | 270                         | 12                                  |

From the above three sets of data, it can be found that the outbound trains are greatly affected by the main line operational trains. With increase of the main line traffic density, the number of outbound trains per unit time continues decreasing. In Fig. 8, the time of the section occupied by the main line trains is indicated by the black area, and the white area in the middle indicates that the section is free. It can be seen that in the case of different main line traffic densities, the "interval 1" with the smallest operation interval has the shortest free time for each track, and the time period available for outbound trains is the smallest. While the "interval 3" with the largest operation interval has the longest free time each track, and the time used for the outbound train is also longer. Undoubtedly, the smaller tracking interval increases the difficulty of exiting depot.

Figure 8. Schematic diagram of track occupation

Considering the main line operational trains, the access line capacity is sufficient, and the exit capacity of depot is mainly limited by the main line passing capacity. The main line occupancy time can be divided into three parts: the main line occupancy time, the outbound trains occupancy time, and the track free time. And one of the main line trains and outbound trains occupy the track for a fixed time. When the number of operational trains on the main line increases, the time available for the outbound trains is reduced, and the number of outbound trains decreases. what’s more, the converse is also true. 

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From the above analysis, it can be seen that in actual operation, the access line capacity is greatly vacant, and adopting the way of single access line to exit depot can often meet the operational needs.

4. CASE ANALYSIS OF TAIPINGHU DEPOT

Taipinghu Depot is located in downtown Beijing and is a depot attached to the Second Ring Line of Beijing Metro. It covers an area of 12 hectares, which is the smallest depot in the existing depot [8].

![Figure 9. Satellite image of Taipinghu Depot](image)

As shown in Fig. 9, the Taipinghu Depot is a stub-end depot. There are 24 tracks in the two operation depot, and each track adopts a dual-row design. The access lines are connected with both ends of the "eight" shape in a three-dimensional manner, one line is adjacent to Xizhimen Subway Station, and the other line is adjacent to Jishuitan Subway Station, as shown in Fig. 10 [9].

![Figure 10. Schematic diagram of connection about access lines](image)

4.1 Train Exit Capacity of Depot at This Stage

From 16:40 to 17:40 on one day, in the direction of the outer ring of Beijing Metro Line 2, the arrival time of subway trains (excluding outbound trains) at Xizhimen Subway Station is shown in Table 4. In order to ensure a certain level of operation, the depot needs to complete 10 trains operation of exiting depot between 16:40 and 17:00. Table 4 shows the time from the train operating on the main line to entering the Xizhimen Subway Station.

On the basis of using the satellite image and distance measurement function or location information of depot provided by Baidu Maps, a simulation model is constructed through Anylogic software to simulate the situation of exiting depot in Taipinghu Depot, the tracks of the Taipinghu Depot and adjacent areas are shown in Fig. 11.

| Number | Arrival time | Number | Arrival time |
|--------|--------------|--------|--------------|
| 1      | 16:40:00     | 9      | 17:15:29     |
| 2      | 16:49:12     | 10     | 17:19:22     |
| 3      | 16:45:25     | 11     | 17:21:20     |
| 4      | 16:54:49     | 12     | 17:25:15     |
For 10 outbound trains, the time of exiting the operation depot (the time of route when the outbound trains start to arrange from the operation depot), the time of exiting depot (the time when the outbound trains enter the main line), and the time of arriving station (The time of outbound train arriving at Xizhimen Subway Station) are counted (using simulation time, simulation time 0 o'clock represents the actual time 16:30), as shown in Table 5.

**TABLE 5. STATISTICS OF EXITING DEPOT**

| Number | Time of exiting operation depot(min) | Time of exiting depot (min) | Time of arriving station (min) | Operation time in depot(min) | Interval of exiting depot(s) |
|--------|-------------------------------------|-----------------------------|--------------------------------|-----------------------------|----------------------------|
| 1      | 8.33                                | 12.88                       | 14.18                          | 4.55                        |                            |
| 2      | 13.22                               | 17.73                       | 19.03                          | 4.51                        | 291                        |
| 3      | 18.06                               | 22.61                       | 23.91                          | 4.55                        | 293                        |
| 4      | 22.94                               | 30.09                       | 31.39                          | 7.15                        | 449                        |
| 5      | 30.43                               | 35.09                       | 36.39                          | 4.67                        | 300                        |
| 6      | 35.43                               | 39.95                       | 41.24                          | 4.52                        | 291                        |
| 7      | 40.28                               | 47.09                       | 48.39                          | 6.81                        | 429                        |
| 8      | 47.42                               | 53.09                       | 54.39                          | 5.67                        | 360                        |
| 9      | 53.43                               | 57.97                       | 59.27                          | 4.55                        | 293                        |
| 10     | 58.31                               | 63.11                       | 64.41                          | 4.80                        | 308                        |
| 11     | 63.35                               | 70.42                       | 71.39                          | 7.07                        | 419                        |

From the simulation results, it can be seen that Taipinghu Depot can launch 10 new trains in the outer ring direction within the specified time, which meets the need of actual operation. In the simulation, the situation of the 11th train exiting depot is also simulated, and it is found that the time of the train exiting depot has exceeded the requirement of the specified time period. The newly launched 10 trains on the outer ring of the depot have reached or approached the limit of the exit capacity of depot in the trains route way in many times.

In actual production, the average interval of exiting depot is 338s, and the average interval of exiting depot is 335s in the simulation. The simulation results are better in line with the actual situation.
4.2 Optimization about Exit Capacity of Depot

The average interval between adjacent operational trains on the main line is 225s. After subtracting the minimum train tracking interval, the free time of main line for trains exiting depot is relatively small, which greatly limits the exit capacity of depot. When optimizing the exit capacity of depot, start with completing as many train exiting depot as possible in the track free time. Exiting depot adopts the trains route way in many times, the single departure signal is set up in the middle of the access line, the location is shown in Fig. 12.

![Figure 12. Setting situation of single departure signal](image)

Under the current operation density of the main line, the situation of exiting depot in Taipinghu Depot with the single departure signal set at 16:40 to 17:40 is simulated. The optimized data of exiting depot is shown in Table 6.

| Number | Time of exiting operation depot(min) | Time of exiting depot (min) | Time of arriving station (min) | Operation time in depot(min) | Interval of exiting depot(s) |
|--------|-------------------------------------|----------------------------|-------------------------------|----------------------------|-----------------------------|
| 1      | 8.33                                | 12.88                      | 14.18                         | 4.55                       | 253                         |
| 2      | 11.02                               | 17.10                      | 18.40                         | 6.08                       | 240                         |
| 3      | 13.67                               | 21.09                      | 22.39                         | 7.42                       | 239                         |
| 4      | 17.44                               | 26.11                      | 27.40                         | 8.66                       | 301                         |
| 5      | 21.44                               | 30.09                      | 31.39                         | 8.65                       | 240                         |
| 6      | 26.45                               | 35.09                      | 36.39                         | 8.64                       | 300                         |
| 7      | 30.43                               | 39.09                      | 40.39                         | 8.66                       | 240                         |
| 8      | 35.43                               | 43.09                      | 44.39                         | 7.66                       | 240                         |
| 9      | 39.44                               | 47.10                      | 48.40                         | 7.67                       | 241                         |
| 10     | 43.43                               | 53.10                      | 54.40                         | 9.67                       | 360                         |
| 11     | 47.45                               | 57.09                      | 58.39                         | 9.64                       | 240                         |
| 12     | 53.44                               | 63.10                      | 64.39                         | 9.66                       | 360                         |

After optimization, the depot can complete the 12 trains operation of exiting depot within the specified time period. Compared with the existing situation, the exit capacity of depot in the specified time period is increased by 2 trains, which proves that the exit capacity of depot in Taipinghu Depot can be improved during the 16:40-17:40 period by adopting the trains route way in many times and set up the single departure signal in addition.

The bottleneck point of exit capacity of depot in Taipinghu Depot is the main line capacity. The high-density main line operational interval results in small free period of the main line track. The optimizing key of adopting the trains route way in many times is to reduce the interval of adjacent trains and make more trains enter the main line in the same free time.
5. SUMMARY
This article takes urban rail transit train's exit capacity of depot as the research object, and comprehensively analyzes the exit capacity of depot from the key links of exiting depot. Taking the Taipinghu Depot as an example, the existing exit capacity of depot is analyzed, bottleneck is pointed out, and relevant optimization scheme is proposed and verified.

(1) The paper introduces the operation methods and processes of exiting depot in detail;
(2) The paper studies the train's exit capacity of depot from the perspectives of the access line and the main line. Through simulation method, the exiting depot’s models under different conditions are constructed, and the influences of the access line and the main line on the exit capacity of depot under different circumstances are studied.
(3) The paper takes the situation about exit capacity of depot in Taipinghu Depot as an example, analyzes the use of the existing exit capacity of depot, points out the existing bottleneck, proposes the optimization scheme for the exit capacity of depot in Taipinghu Depot, and the effectiveness of the scheme is verified by simulation.

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