Virtual Dynamic Marshalling of Trains under Severe Epidemic Situation

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Abstract: In the context of the global epidemic, urban rail transit has the risk of spreading the virus. Taking Beijing Metro Line 1 as an example, this project establishes a dynamic model of train variable marshalling by studying passenger behavior and virus transmission, aiming to explore more intelligent marshalling mode, optimize transportation organization, and improve the flexibility of train marshalling and dispatching of urban rail transit, so as to improve its transportation efficiency and reduce the station personnel density, Then reduce the risk of disease infection of passengers in the process of taking urban rail transit under the background of the outbreak. The results show that: Dynamic marshalling technology can significantly improve the transport efficiency of urban rail transit trains and effectively control the risk of infection of passengers.

Keywords: urban rail transit, virtual dynamic marshalling, epidemic

1.   Introduction

After the outbreak of the Covid-19 epidemic, urban rail transit has taken on many people, resulting in a huge hidden danger of virus transmission, which has brought great hidden danger to the epidemic prevention and control. The subway stations and carriages are relatively closed and crowded places and are facing unprecedented pressure. These measures have reduced the operational efficiency of urban rail transit to a certain extent and brought inconvenience to people's travel. Therefore, this study takes this contradiction as the starting point to explore an operation mode that can prevent and control the epidemic and reduce the risk of epidemic transmission while ensuring the transportation capacity. This research takes train marshalling and dispatching as the research object and studies the dynamic train marshalling and dispatching method based on virtual marshalling under major epidemic situation. The purpose of this project is to explore more intelligent marshalling methods, optimize transportation organization, and improve the flexibility of train marshalling and dispatching of urban rail transit, to improve its transportation efficiency, reduce the density of personnel at the station, and reduce the risk of disease infection of passengers in the process of taking urban rail transit in the context of the epidemic outbreak.

2. Risk Analysis of Subway Epidemic Transmission

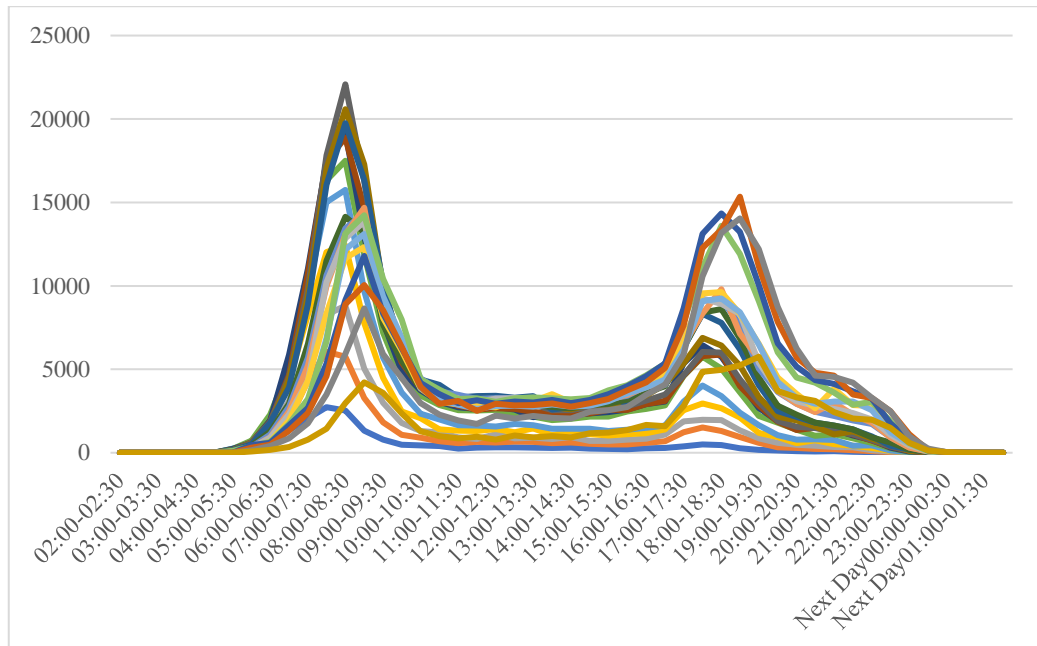### 2.1. Analysis of Passenger Flow of Beijing Line 1

Figure 1: Time-sharing section passenger flow of Line 1(up-direction).

2.1.1. Time Distribution Characteristics

According to Figure 1, the time distribution of rail transit passenger flow is inseparable from the regularity of urban residents' travel time. With the change of urban life rhythm, the hourly passenger flow of rail transit is distributed in a hump shape in one day, with two peaks. Among them, the morning peak of going to work and school appears at 7:30~8:30; The evening peak is formed after work and school in the afternoon, which occurs from 17:30 to 19:00, and the passenger flow is flat peak in other time periods. A series of data of time-sharing section passenger flow of rail transit reflect the distribution and change of hourly passenger flow in a day.

2.1.2. Passenger Travel Characteristics

The average travel distance and transfer times of passengers are large. As a high cost and efficient fast transportation tool, the subway should play a key role in all modes of urban transportation, mainly attracting long-distance passengers. According to the survey [1], the average travel distance of Beijing subway passengers in the subway network is about 12 kilometers, indicating that passengers choose the subway to travel with obvious long-distance characteristics, and the backbone role of the subway in the transportation network is initially emerging.

2.2. Analysis of Subway Passenger Movement Behavior

The passenger flow of the subway rail transit station platform has the following particularity:

(1) Due to the limitations of equipment and facilities, passenger walking channels and other service facilities in the subway station, passengers' walking and pathfinding behaviors in the subway station are normative, and the walking space is limited, and the main direction of action is guided by the lines in the subway.

(2) The pedestrian flow at the platform level in the subway passage mainly concentrates at the entrance and exit stairs and escalators, the entrance and exit of transfer facilities and narrow passages; In addition, when the subway train arrives, a large number of passengers will rush into the train, which will also cause congestion.

2.3. Analysis of Subway Epidemic Situation

According to the social force model [2], with the increase of the total number of people leaving the station, the number of contacts between pedestrians and the number of infected people will increase. Under the same conditions, the fluctuation range of contact number results is larger. It may be due to the following effect of pedestrians. Because of the following effect, most of the infected people are pedestrians around the initial infected people, so the location of the initial infected people will have an important impact on the number of infected people.
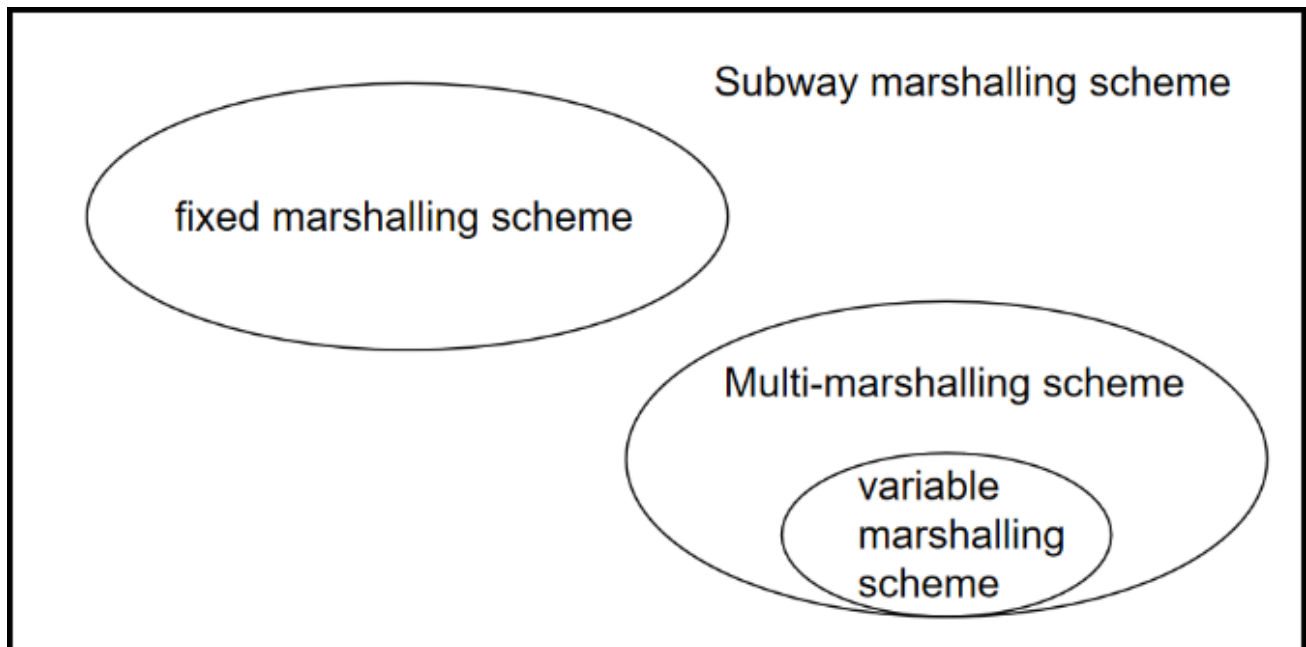
3. Marshalling Mode

Figure 2: Relationship between different marshalling schemes.

3.1. Fixed Marshalling Scheme

Fixed marshalling is also called single marshalling, that is, fixed marshalling is adopted in different operation stages, such as 6-car marshalling, 8-car marshalling, etc. The coping strategy for different passenger flow periods is to adjust the number of trains running.

3.2. Variable Marshalling Scheme

Variable marshalling scheme is a special form of multi-marshalling scheme, that is, flexible marshalling [3]. Similarly, for the rail transit passenger flow with poor balance and obvious travel time, the fixed large and small marshalling trains in the multi-marshalling scheme are given the ability of flexible decoupling and reconnection, that is, the trains will undergo online decoupling at specific transfer or branch nodes, or offline decoupling at the end of the line; This scheme is flexible and highly matched with the change of passenger flow [4].
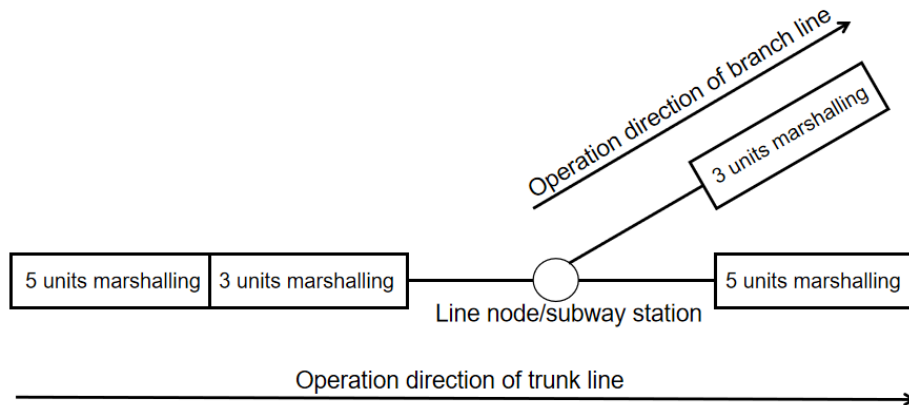
Figure 3: Schematic diagram of subway unmarshalling of Y-type line.

3.3. Multi Marshalling Scheme

Table 1: Specific forms of multi-formation schemes in various countries.

Multi Marshalling Scheme	Nationality	Line	Marshalling Scheme
Consider the marshalling scheme during the operation period (morning or afternoon)	China	Guangzhou Metro Line 3	Two 3-unit marshalling
	France	French Metro	3/6/9 unit marshalling in different time
	Austria	Vienna U-Bahn	4/8 unit marshalling in different time
Consider the marshalling scheme during the different direction (close or far traveling)	China	Shanghai Metro Line 1, 2	Mixed 6-unit & 8-unit marshalling
		Shanghai Metro Line 8	Mixed 6-unit & 7-unit marshalling
	Japan	Inside line of Tokyo Maruki	Mixed 3-unit & 6-unit marshalling
	Japan	Tokyo Deputy Metropolitan Line	Mixed 8-unit & 10-unit marshalling
	France	Paris Line 6, 11	Mixed 4-unit & 5-unit marshalling
	United States	New York Subway	8/11 excessive Marshalling

We plan to adopt the public transit operation mode for urban rail transit. Each line will formulate the train operation schedule according to its own passenger flow characteristics, reasonably plan the train shifts, effectively control the passenger flow, use energy, and complete the efficient passenger transport task.

4. Dynamic Model of 3-train Variable Formation

Single vehicle driving on the line can be regarded as a general catch-up problem in the study and is constrained by the minimum safe distance [5], running speed and braking and traction capacity in the process of driving.

Reasonable assumptions:

1. The dynamic marshalling train is composed of a specified number of train sets. The running speed, acceleration, braking performance and passenger capacity of each train are identical.

2. Each independent train has the same length.

3. The state of formation establishment occurs and changes instantaneously or within a fixed time (without considering the interference generated in the process of delayed communication or mutual information or determining the delay time in advance).

4. After two train sets reach the minimum operation interval during the formation process, they shall be regarded as a stable train set unit.

5. When two train sets are greater than the braking safety interval during the formation process, they are immediately considered as two independent train set units.

Based on the above reasonable assumptions, the variable marshalling scheme can be described, and the basic dynamic model can be established.

4.1. Model Establishment

Based on the above reasonable assumptions, the variable marshalling scheme can be described and the basic dynamic model can be established.

Relative speed of train set:

$$|v_{i-1} - v_i| \leq thv \tag{1}$$

Relative distance of train set:

$$p_{i-1} - p_i - al_{i-1} - d_{i-1,i}^{ref} \leq ths \tag{2}$$

The above two formulas are used as the criteria for variable marshalling.

Operating speed constraint:

$$0 \leq v_{k+i|k} \leq v_{max} \tag{3}$$

Minimum safety distance constraint:

$$d_{min} \leq d_{k+i|k} \tag{4}$$

Traction and braking capacity constraints:

$$-P_{bre} \leq v_{k+i|k} * v_{k+i|k} \leq P_{acc} \tag{5}$$

Maximum number of groups constraint:

$$a_{max} \leq \frac{L_S}{l_{k+i|k}} \tag{6}$$

The state equation of single unit:

$$\begin{cases} \dot{p}(t) = v_{i(t)} \\ vi(t) = -\rho[a + bv(t) + cv^2(t)] + \rho v(t) - \rho \omega_i \end{cases} \tag{7}$$

In these above formulas, v_i is the stable running speed of train set i, thv is the maximum relative speed of train formation, p_i is the position of train head i of the train set, l is the train length, a is the number of trains, ths is the maximum relative distance of trains, d is the train operation interval, L_S is the length of platform S. ρ Is the resistance correction coefficient, $a/b/c$ is the coefficient of Davis empirical formula, ω_i refers to the environmental resistance of the train set i during stable operation.

4.2. Model Solution

The model is solved directly for every 10 minutes and every 5 minutes, and the conclusion is as follows.
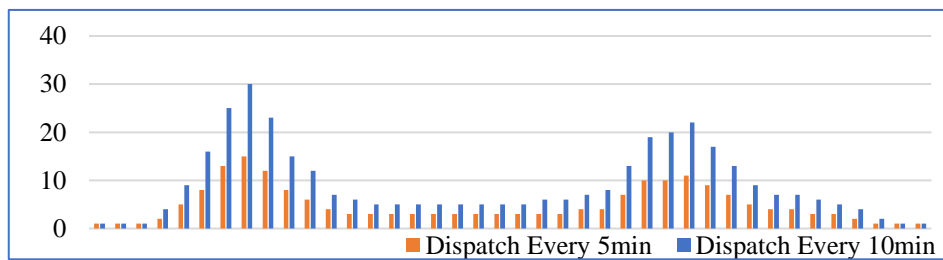

Figure 4: Number of train formation when entering the station.

The handling during the normal and peak periods is relatively simple, and departure at the frequency of 10 minutes/shift during the peak period will seriously affect the operation of the subway. Therefore, use the high frequency departure scheme in the peak period, and use the low frequency departure scheme in the flat or low peak area to maximize the occupancy rate of each carriage.
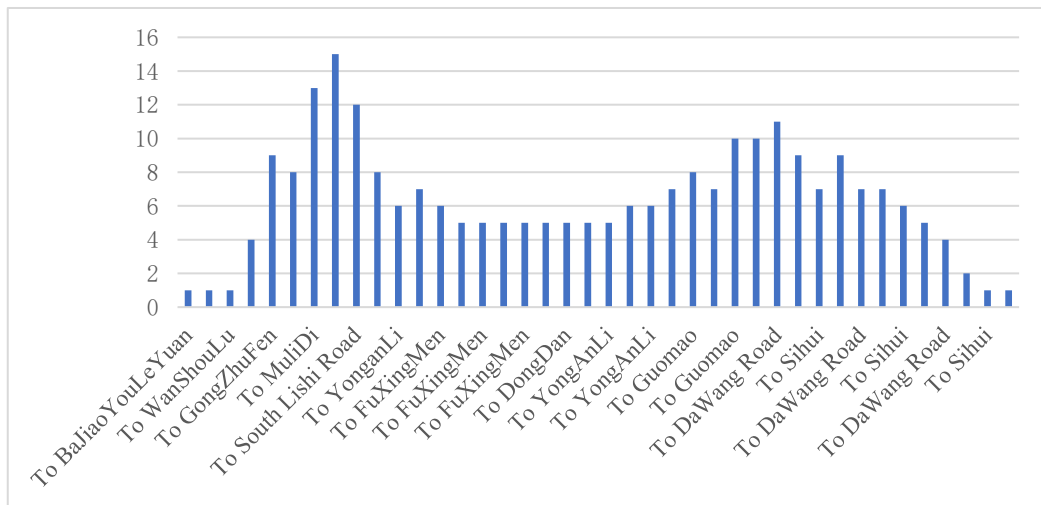

Figure 5: The final mixed marshalling scheme.

It is concluded that the mixed marshalling scheme can be obtained by changing the marshalling scheme at 7:30 11:00 17:00 19:30.

5. Dynamic Marshalling Adjustment

Due to the large difference in passenger flow between peak hours and peak hours, the passenger flow at different stations also varies greatly [6]. If the mode of marshalling adjustment can be added during the conversion between high and low peaks and when the train passes through different stations during operation, it can effectively improve the full load rate of the train and reduce energy consumption.

5.1. Formation Adjustment during Peak and Off-peak Periods

Generally, during the smooth transition period from early peak to flat peak, the running interval can be adjusted from one turn-back end, and then the marshalling adjustment can be made when the large interval train runs to another turn-back end [7].

The marshalling is from long marshalling to short marshalling, and the long marshalling trains need to be unmarshalled. The train unmarshalling process is as follows:

(1) The coupled train stops at the parking point in the unmarshalling area in the automatic driving mode according to the plan.

(2) The south signal system sends the decoupling command, or the driver presses the decoupling button to unlock the coupler.

6. Conclusion

Through comparative analysis, the dynamic marshalling train set has undergone a lot of optimizations and innovative design and has certain advantages. Based on digesting and absorbing the LTE scheme adopted in the existing subway line signal system, and summarizing years of operation and maintenance experience, the dynamic marshalling train has improved the utilization ratio of the train, greatly reduced the waste of resources, and also improved the convenience and comfort of passengers.

6.1. Adaptability Advantages

The manufacturing platform of dynamic marshalling train sets with different speed grades can adjust the number of marshalling according to the actual operation requirements, and manufacture the train sets according to the design speed requirements of the line to meet the needs of different lines such as intercity, short-distance transportation, routing, and crossline transportation between different lines.

6.2. Economic Advantages

By increasing or reducing the number of cars, dynamic marshalling train sets can improve the utilization rate of passenger carrying capacity cars, improve the operation efficiency and reduce the per capita operation cost.

6.3. Maintenance Advantages

The dynamic marshalling train set's motor car and trailer can be disassembled and replaced, which can shorten the maintenance time of the faulty train, realize the two standby modes of single train and the whole train, and reduce the standby rate of the whole train; It can realize the replacement maintenance of single vehicle, greatly reduce the time for advanced maintenance of multiple units, and improve efficiency.

6.4. Application Prospect

Considering the instability of passenger flow forecast, the improvement of future social living standards, the unexpected development of the subway system and other factors, according to the actual situation of the line, it is suggested to carry out the configuration of phased development and reserve a certain reserve capacity, which not only realizes the maximization of construction investment and operation income, but also provides a feasible idea for the sustainable development of the subway system.

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