Research on Emergency Evacuation of Urban Rail Transit

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Abstract: With the expansion of urban scale and the increase of travel distance, people become more and more dependent on rail transit. During rush hour, a large number of passengers choose rail transit as their travel mode. However, in some emergencies, rail transit may also be interrupted, which will not only cause a large number of travel delays for passengers, but also cause a large number of passengers to gather inside the rail transit station in a short time, increasing the probability of stampede. Therefore, the use of connecting buses to evacuate stranded passengers has become a research hotspot of evacuation problems, which is of great significance to public safety and emergencies, the reduction of passenger delay incidents and the reduction of economic losses.

1. Research background and significance

The development of the city promotes the continuous expansion of the city scale, and people's travel distance also increases continuously. The increasing travel demand puts great pressure on the limited road resources in the city. Therefore, in order to achieve a balance between traffic demand and traffic supply, it is inevitable to encourage the development of public transportation. Rail transit, with its large capacity, safety, punctuality and speed, stands out among various public transport modes.

Urban rail transit in China has a relatively late start, and the speed of construction is relatively slow. The first phase of Beijing metro is China's first subway line, which was completed and opened to traffic on October 1, 1969. Since the reform and opening up, many rail transit construction projects have sprung up in China's major cities, and the length and mileage of rail transit operation lines have steadily increased. In recent five or six years, the rapid development momentum has been in China's urban rail transit construction. During the 12th five-year plan period, investment in rail transit has reached 900 billion yuan, and the length of the railway has exceeded 2,000 kilometers. By the end of 2014, China has built and operated rail transit lines in Beijing, Tianjin, Hong Kong, Guangzhou, Harbin, Dalian, Shanghai, Taipei, Wuhan, Zhengzhou, Nanjing, Kaohsiung, Chongqing, Shenzhen, Shenyang, Xi 'an, Suzhou, Chengdu, Foshan, Kunming, Changsha, Ningbo, Hangzhou, Changchun and Wuxi. Meanwhile, due to the rail transit in 2020, the average construction needs to be completed within the 13th five-year plan period. [1] It can be seen that the rapid development trend still exists in the rail transit field. More and more passengers need to be borne by the urban rail transit system. Meanwhile, the proportion of passenger transport in the urban rail transit is also increasing. Therefore, urban rail transit has become the most important component of the urban public transport passenger transport system.

Because of the rapid development of rail transit, people's life has become more convenient and faster. New York's subway system carries about five million passengers a day, Paris's about six million and Mexico's nearly eight million. Such a large passenger volume makes it relatively difficult for the rail transit system to evacuate passengers in case of unexpected events. Because the rail transit is different from the regular bus on the ground, if the regular bus breaks down, it can be replaced by other buses running on the same route, which will not cause serious consequences. However, once the rail transit breaks down, all the running vehicles on the track will be affected and cannot be replaced by other running vehicles on the same route.

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2. Conventional countermeasures for rail transit emergencies

In the introduction, it is pointed out that the current rail transit management departments usually only provide emergency connections to stations within the fault zone when dealing with emergencies. This section introduces the routine countermeasures of the rail transit management departments in the case of rail transit emergencies.

2.1 Train operation adjustment strategy

As a complex and relatively closed system, the urban rail transit system often shows partial interruption after an emergency, which means that some stations and sections in the rail transit line are out of service. At this time, the operation adjustment of rail transit trains should be carried out. At present, the emergency train operation adjustment plan is mainly formulated by the relevant departments of urban rail transit operation management. [2] According to whether it is an interrupted station or section, it can be roughly divided into operation adjustment of interrupted line and operation adjustment of uninterrupted line.

2.1.1 The line interrupted

There are two kinds of railway transit train operating routes: general and regular routes (single routes) and special routes. Special junctions include nested junctions, articulated junctions and staggered junctions. The original connectivity of urban rail transit system will be destroyed by the suspension of some stations and sections, resulting in the disruption of the original traffic organization plan and the failure of normal operation of trains with interrupted lines. At this time, the rail transit system takes the principle of reducing the loss of transport capacity to the greatest extent, giving full play to the line infrastructure, ensuring the normal operation of the lines in the non-suspended sections and passenger flow distribution as the principle, and adjusts the train operation plan of rail transit, namely, adopting the “special route”. The specific adjustment scheme is as follows: search the nearest reentry station along the railway traffic line from the distance to the interrupted station and the interval at both ends, and run the temporary transit train, that is, implement segmentalized operation on the original railway traffic line.

2.1.2 The line not interrupted

The normal operation of the uninterrupted section of rail transit lines can be guaranteed by running emergency temporary roads in the interrupted section. However, due to the impact of unexpected accidents, the interruption of the line will lead to insufficient capacity, and a large number of passengers are stranded at the junction of the interrupted line and the uninterrupted line, resulting in the increase of the uninterrupted line passenger flow. [3] In order to mitigate the impact of sudden interruption events on urban rail transit system, relieve the passenger flow pressure on the uninterrupted lines and improve its transport efficiency, it is necessary to adjust the train operation plan of the uninterrupted lines associated with the interrupted lines according to the actual situation. In case of sudden interruption of urban rail transit, the train operation adjustment scheme of the uninterrupted line mainly includes the following four aspects: 1) train marshalling scheme; 2) train routing scheme; 3) train stop plan; 4) traffic scheduling plan.

2.2 Bus emergency response linkage strategy

2.2.1 Adjust the line

The two most important components of urban public transport system are urban rail transit and ground conventional bus. In addition, rail transit and public transport have different operational characteristics and technical advantages, so they undertake different passenger transport tasks in the urban transport system at ordinary times. In the establishment of rail transit system, the coordination and connection between rail transit and conventional bus are also important goals to be considered. In case of sudden interruption of urban rail transit, the short-term replacement of rail transit can be given due consideration to the use of bus lines around rail transit stations and some bus lines that are basically in line with the operation of rail transit.

1) when the rail transit conventional connection station (or the line where the conventional connection station is located) is suddenly interrupted, if the conventional connection line has surplus capacity, the conventional connection line can partially replace the transport function of rail transit. Specifically, the conventional connection line should be adjusted to extend to both ends of the interruption interval. The running line can refer to the running line of rail transit.

2) sudden interruption when rail transit line range interval trend is consistent with the original bus lines part, if the line capacity is enough, can be reference to the practice of the conventional feeder, by shortening the departure interval of bus lines, appropriate adjustments to bus routes, to make it as a can temporarily replace the rail transit line bus operation, shutdown interval according to actual situation put on extra buses.

2.2.2 Open the line

The public transport emergency linkage system of urban rail transit system should not be regarded as two isolated parts. [4] When the urban rail transit breaks down suddenly, the two parts should be considered in a comprehensive way to make it a complete system. At the same time, according to the actual situation of sudden interruption events, the development of targeted, effective, operable operation plan. Usually, there are two main modes of emergency bus line operation in case of sudden interruption.

1) Operate in accordance with the responsible area

Although unexpected events may cause only a part of the station service, then the city's traffic system as a whole, inescapably, part of the station or the range of service can lead to paralysis to the several different locations in the system, then, for the most efficient solve the traffic problems in the different position, can take the whole city into several area, each area is responsible for his internal traffic emergency connection and evacuation. The setting of responsibility area is to allow each responsibility area to arrange and plan emergency connection and evacuation schemes by itself. The advantage lies in that the bus capacity in the responsibility area is considered as a whole. That is to say, the bus capacity in the responsibility area is fully utilized, which can reduce the operating cost of emergency connection buses.

2) Start the line instead of interrupt section

In essence, it can be seen as a short-term replacement for rail transit by emergency transit buses. In fact, the bus ferries run within the interruption interval of urban rail transit, and the bus stops at the same stations as the rail transit. In this way, the evacuation of passenger flow within the interruption interval of rail transit can be completed, and the continuity of rail transit transport lines can be guaranteed. In addition, it can also effectively connect with the rail transit stations still in operation, so as to relieve the pressure of passenger flow caused by insufficient transport capacity of rail transit.

3. Analysis of factors influencing passenger choice behavior in emergencies

When an emergency happens in rail transit, passengers can choose alternative travel modes including regular bus, rail transit transfer, taxi and online ride-hailing, walking, cycling and sharing bikes, emergency bus transfer, etc. On the one hand, passengers' choice behavior will affect how many passengers choose to transfer and how many passengers choose to stay at the original station when an emergency occurs in rail transit. On the other hand, it will also affect how many passengers choose to take the shuttle bus after the emergency shuttle bus is started. Therefore, the analysis of passenger choice behavior is very important. [5] Which transfer mode passengers choose will be affected by the following aspects:

3.1 Travel purpose

The purpose of travel will affect passengers' requirements on travel time, connection time and comfort. For example, if passengers travel for entertainment that requires less time, such as shopping and sightseeing, they are more likely to wait for the resumption of rail transit at the original station, or choose nearby buses to arrive at the destination. If the travel purpose of passengers is to commute or take a plane or high-speed train, then passengers have a higher requirement on the accuracy of time. At this time, even though they pay a large economic cost, passengers will choose taxi and other travel methods.

3.2 Travel distance

Travel distance also affects the transfer behavior of passengers. For example, if the waiting time is not long and the passengers still have a long distance to reach the destination at the original station, then the waiting time in the middle is relatively small. Considering that it is tedious to transfer to other means of transportation, the passengers tend to wait in place. If the waiting time is long, passengers may choose to transfer to public transportation, because of the high economic costs such as taxis.

3.3 Socio-economic attributes of passengers

The gender, age, occupation and family income of passengers can be summarized as the socio-economic attributes of rail passengers. In the case of sudden rail transit, passengers' social and economic attributes will also affect their requirements for travel time, comfort and other factors, so these factors will also affect passengers' transfer behavior. For the elderly passengers, for example, frequent change in their physical challenge is bigger, so they may prefer to wait for rail transit troubleshooting, and not to choose a faster to travel in a short period of time to adapt to a variety of ways of transformation, is likely to prefer to wait for rail transit troubleshooting, and not to choose more effective ways of cohesion. For young passengers with better physical conditions, the transfer is not troublesome, and they tend to choose the faster transfer mode.

4. Design of emergency transit evacuation plan

4.1 Evacuation demand analysis

In the design of evacuation plan, the analysis of evacuation demand is very important. In the subsequent allocation of evacuation resources, evacuation demand will be taken as an important parameter to be included in the analysis.

Here, the analysis of evacuation demand still USES rail transit station as the smallest unit and studies the travel behavior of rail transit passengers.

For the overall evacuation demand, it is not easy to sum up the evacuation demand of all rail transit stations. For rail transit stations located at both ends, only passengers of one endpoint will be accepted in one trip of emergency bus connection. [6] Therefore, when calculating the overall evacuation demand, only one endpoint will be included in each trip, and the evacuation demand of each trip will be calculated separately. Finally, take the larger of the two seats and the overall evacuation requirements.

4.2 Evacuation route design

The purpose of evacuation by emergency transit buses is to evacuate people stranded by rail transit emergencies in the shortest possible time under the constraint of limited resources. Therefore, the design of evacuation route should be based on the shortest travel time of passengers.

At the same time, the role of emergency transit is to replace the original rail transit, guarantee the connectivity between the interrupted stations, and enable the stranded passengers to cross the interrupted interval through the transit. Therefore, in the design of evacuation routes between stations, emergency transit buses should refer to the rail transit and circulate among the interrupted rail transit stations. At the same time, it should be as close as possible to the direction of the original rail transit. That is to say, if there are roads on the ground that exactly coincide with the rail transit lines, such roads should be the priority. If the road pattern on the ground does not coincide with the route of rail transit, then the evacuation path selected should be as close as possible to the original rail transit route. Of course, such a design also has a premise, that is, if the original road congestion is serious, then we should try to avoid too congested roads.

Through the above analysis, the shortest circuit algorithm is adopted to calculate the design of evacuation path between stations. [7] At the same time, considering that the distance between adjacent rail transit stations is often short, the delay at the intersection should not be ignored, but should also be included in the calculation of time cost, which is calculated by Webster model method here.

4.2.1 Introduction of shortest circuit algorithm

The shortest path is designed to solve the shortest path problem. The so-called shortest circuit problem is that in a network, the length of the line between adjacent nodes is known, and it is necessary to find a path with the shortest length from a certain starting point to a certain end point. When the rail transit stations are Abstracted into nodes and the roads between stations are Abstracted into networks, it is a shortest circuit problem seeking the shortest time from the starting point V1 to the end point Vn.

4.2.2 Webster model method

In the rail transit stations, the distance between the two stations is generally close, so the delay of the intersection has a great impact on the determination of evacuation route, so the delay of the intersection is included in the calculation of the shortest evacuation route. The Webster delay model proposed by Webster in 1958 is used here.

Webster delay model is the most widely used intersections delay model in mainland China. It was widely used after TRB launched capacity manual 2000 (HCM2000). The model consists of uniform delay, random delay and initial queue delay. The formula is as follows:

$$d = d_u + d_r + d_c$$

4.2.3 Determination method of shortest evacuation path

Since the shortest circuit problem here is to find the shortest circuit problem from the starting point V_1 to the end point V_n, Dijkstra algorithm is adopted. However, different from the traditional Dijkstra algorithm, due to the delay of intersections, the node still has the right of way when it is Abstracted into a network diagram. Meanwhile, considering that the delay of each lane in different directions is different within the intersection, the delay of this node is considered to be equal to the mean of the delay of each lane for the convenience of calculation, which is taken as the weight of this node to be included in the calculation of the shortest circuit. The specific calculation method is as follows:

So, we're going to start with V_1, and we're going to give each vertex a number, and we're going to call it a label, and we're going to call it a label, T label and P label. The T label, which represents the last version of the shortest right of way from the starting point V1 to this point, is called the temporary Table number; The P label represents the shortest right of way from V1 to this point, called the fixed label. I'm not going to change the point where I have a P label, and I'm going to put a T label on the point where I don't have a P label on the Table. Every step of the algorithm changes the T label at a certain point to the P label. After a finite number of steps, all the points can be labeled with P, that is, the shortest right of way from the starting point to each point can be obtained. The calculation steps are as follows.

(1) label V_1 with P, $P(1) = d_1$, and d_1 represents the weight of node 1. $T_0(j) = +\infty$ is equal to plus infinity means that the shortest right of way from V_1 to V_1 is 0, and the upper bound of the shortest right of way from V_1 to each point is $+\infty$. In the label, the number in brackets represents the dot, and the corner code 0 represents the initial value.

(2) suppose V_i is the point where the label of the previous round (the label of the k-1 round) has just obtained the label of P, then conduct a new round of label (the K round) for all the points that have not obtained the label of P. Considering all points V_j adjacent to V_i that are not labeled with P label, modify the T label of V_j to be:

$$T_k(j) = \min[T(j), P(i) + d_{ij} + d_j$$

5. Summary

Urban rail transit has the advantages of high punctuality rate, large traffic volume, safety, rapidity, green environmental protection, etc., which plays a great role in easing urban traffic congestion. However, urban rail transit has also become an important target of terrorist attacks, especially in foreign countries. In recent years, the frequent occurrence of malignant emergencies in urban rail transit seriously threatens the safety of people's lives and property, which has raised important warnings for the safety of urban rail transit in China. In view of this, this paper makes an in-depth study on emergency management and evacuation simulation of urban rail transit, which has important theoretical value and practical significance.

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