Research of emergency feeder bus scheme for urban rail transit under unexpected incident

Jiarui Liu¹, Xianyu Wu²

¹²School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

Abstract. Because of rail transit’s fixed track, once the normal operation is interrupted due to unexpected events, a large number of passengers will be detained. The application of scheme for emergency feeder bus which include not only bus dispatching, but also the scheme of bus line operation is an efficient way to evacuate detained passenger when the rail transit is held up. To solve the problem of emergency feeder bus, it is suggested that the scheme of the bus dispatching and bus route layout be proposed on the basis of determining the affected passenger flow and analyzing the selection behavior of passengers. Based on the bus emergency reserve point, the transfer algorithm is proposed. An emergency bus route layout model is established, in which passengers who do not choose emergency bus connections are excluded, and corresponding connection schemes are designed. Finally, an example is given, and the result shows that considering passenger choice behavior will save scheduling cost, and the emergency bus transfer plan considering passenger choice behavior has certain practical significance.

1. Introduction

Martins and Pato³ used heuristic algorithms to design the feeder bus network. Kuan et al.² studied and concluded that heuristic algorithm can also solve the problem of feeder bus line design and prove the effectiveness of the algorithm. Zeng³ and Darmanin⁴ respectively proposed an evacuation method for evacuating stranded passengers by combining rail transit with taxi system, rail transit and ground bus. Kepaptsoglou⁵ proposed a method for emergency feeder bus dispatch: dispatching ground-schedulable buses on the basis of finding all alternative connection paths for the interruption site. Teng and Xu⁶ discussed the impact of the stranded passengers on the surrounding road network and discussed the emergency linkage strategy with the ground bus in the case of rail transit interruption. Liang⁷ established a feeder bus line model and a vehicle allocation model based on the objective function of the minimum line influence and the minimum point-to-point connection split time, and designed the emergency connection scheme accordingly. Liu⁸ constructed five typical emergency interruption scenarios, and established the generation model of bus linkage connection line network scheme, and obtained the bus linkage optimization scheme under the line interruption operation.

When providing emergency services, passengers do not always choose to connect with buses. Studying the passenger's choice behavior helps to clarify the evacuation needs and avoid the waste of evacuated resources. This paper divides the affected passengers into four categories, studies the rail transit selection coefficient of different types of passengers in the event of an emergency, and then determines the number of passengers ultimately affected, and adds this selection coefficient to the line design model. The bus emergency connection scheme under the sudden interruption event is designed.
2. Research on passenger choice behavior and evacuation demand under sudden interruption events

2.1. Investigation and analysis of passenger travel behavior under unexpected interruption events

When the rail transit is interrupted, according to the positional relationship between the passenger's travel start and end points and the interruption interval, the affected passenger flow is divided into four types (as shown in figure 1). People's choices cannot be obtained in real time due to factors such as the uncertain accident point, scope and starting point of passengers' travel of sudden interruption events. Therefore, the intention (SP) survey is mainly carried out for passengers' choice behaviors under the assumed situation.

The interrupt interval is between the start and end points
The journey starts and ends in the middle section
The starting point of the trip is in the break interval
The destination of the trip is in the interrupt interval

Figure 1. Schematic diagram of affected passengers

2.2. Determination of emergency connection and evacuation requirements in case of sudden interruption

According to the above-mentioned affected passenger flow types, different types of passenger flow $Q$ are initially determined, and the passenger's selection behavior coefficient $\delta$ in different situations is considered, and the final affected passenger flow number $\delta \cdot Q$ is obtained. Thus, the passenger flow OD matrix is obtained, and the unaffected passenger flow is 0, and the finally obtained passenger flow matrix is a diagonal matrix.

3. Emergency feeder bus scheme

3.1. Distribution of evacuated resources

3.1.1. Determination of departure frequency and capacity. According to the method described in Section 2.2, the number of passengers affected is determined, and the passenger flow after the passenger flow that does not select the bus is selected is $Q$.

\[
n = Q \cdot T \cdot (60 \cdot q_0 \cdot \gamma)^1
\]
\[
T = 120L \cdot v^{-1} + 2a t_h + b_t + t_c
\]

Where $n$ is the number of connected buses; $q_0$ is the rated passenger capacity; $\gamma$ is the rated passenger capacity at a certain service level; $L$ is the length of the final connection interval; $a$ is the number of stops (excluding the two ends of the connection site); $T$ is the departure frequency; $t_h$ is the stop time of each station connected to the bus; $t_t$ is the stop time of the terminal; $t_c$ is the U-turn time.

3.1.2. Feeder bus resource allocation. In real life, when the sudden event causes the rail transit to be interrupted, in order to timely transfer the bus to the vicinity of the demand rail transit station, the specific algorithm is as follows:

The emergency reserve points for arrangable vehicles are $B_1, B_2, B_3, \ldots, B_n$. The number of public transportation vehicles in each emergency reserve is $b_1, b_2, b_3, \ldots, b_n$; the track that needs to be connected to the bus $T$; the traffic stations are $T_1, T_2, T_3, \ldots, T_n$, and the required capacity $N$ is determined by Section
3.1.1. The time between each bus emergency reserve site and the track site to be connected is shown in Table 1.

| Emergency reserve point | T1  | T2  | T3  | ... | Tm  |
|-------------------------|-----|-----|-----|-----|-----|
| B1                      | t_{11} | t_{12} | t_{13} | ... | t_{1m} |
| B2                      | t_{21} | t_{22} | t_{23} | ... | t_{2m} |
| B3                      | t_{31} | t_{32} | t_{33} | ... | t_{3m} |
| ...                     | ...  | ...  | ...  | ... | ...  |
| Bn                      | t_{n1} | t_{n2} | t_{n3} | ... | t_{nm} |

In order to meet the goal of minimum total scheduling time, the model will be solved by the following steps:

Step 1: Arrange the time of each column from the largest to the smallest, and mark the number ①, ② and ③ on the right of each number in the table in the order from the smallest to the largest.

Step 2: From the first line, allocate the vehicles, first assign each line of rail transit stations marked ①, and try to meet all the corresponding rail transit stations marked ① in this row. If the number of buses at this reserve site is insufficient, each rail transit site should be equally divided.

Step 3: Repeat the above steps. For a column with two or more minimum times, since there is more than one reserve car point that can be connected in a short time, we can suspend the allocation of this rail transit station when the vehicle is allocated.

3.2. Emergency feeder bus design

3.2.1. Determination of bus connection interval. It is assumed that there is a return line between the upstream adjacent section of \( n_{i-3} \) and the downstream section of \( n_{i+4} \). The interruption of rail transit is shown in figure 2.

\[
S = n + m_1 + m_2 \quad (3)
\]

\[
m_1 = \text{ceiling} \left( \sum_{a=1}^{n} \sum_{b=1}^{i-3} q_{ab} l_{ab} \cdot \left( \sum_{a=1}^{n} \sum_{b=1}^{i-3} q_{ab} \cdot L \right)^{-1} \right) \quad (4)
\]

\[
m_2 = \text{ceiling} \left( \sum_{a=1}^{n} \sum_{b=i+5}^{i+4} q_{ab} l_{ab} \cdot \left( \sum_{a=1}^{n} \sum_{b=i+5}^{i+4} q_{ab} \cdot L \right)^{-1} \right) \quad (5)
\]

Where \( n \) is the number of rail transit stations between the upstream and downstream turn-back lines in the middle section; \( q_{ab} \) is the passenger flow between the rail transit stations a and b; \( l_{ab} \) is the rail transit length between the rail transit stations a and b; \( L \) is the rail transit Average station spacing. The formula (3) indicates the interval in which the emergency transit bus needs to be connected; the formula (4) and (5) indicate the average ride distance of the upstream and downstream passengers. The final bus connection interval is shown in figure 2.
3.2.2. Determination of evacuation routes. On the basis of the connection model of the bus line\cite{9}, considering the passenger's choice behavior, the emergency feeder bus line layout model with the target's final affected passenger travel cost and the bus operation cost is set up.

- Model establishment:

\[
\min Z = (C_1 + C_2) \cdot \left( \sum_m \sum_i \delta_m \cdot q_g(i) \right)^n \\
C_1 = f\left(L_g\right) + C_d \\
C_d = (L_0 \cdot V + \theta)^p \\
C_2 = \mu T = \mu \cdot \sum_i q_g(i) \cdot t_g
\]

- Constraints:

\[
X_g(n) = g, \quad X_g(n) \in S_g \\
L_{\min} \leq L_g \leq L_{\max} \\
Q \leq Q_{\max} \cdot \eta
\]

Among them: \( C_1 \) is the feeder bus operation cost; \( q_g(i) \) is the passenger flow from the track station \( g \) to the emergency bus station \( i \); \( \delta_m \) is the selection coefficient of different types of affected passengers (\( m=1, 2, 3, 4 \)); \( g \) is Rail transit stations requiring emergency access; \( G \) is the collection of rail transit stations that require emergency access, the distance from the emergency access bus during the connection, \( g \in G \); \( C_d \) is the cost of the bus from the reserve point to the rail transit station that needs to be connected; \( L_0 \) is the distance from the reserve point to the rail transit station that needs to be connected; \( V \) is the running speed of the bus; \( \theta \) is the undetermined coefficient; \( C_2 \) is the time cost of the passenger; \( \mu \) is the time value coefficient; \( T \) is the total time for passengers to take emergency access bus; \( g(t_g) \) is the time cost of the bus from the reserve point to the rail transit station that needs to be connected; \( S_g \) is the set of emergency bus stops that meet the requirements of the first and last stations.

At present, the optimal layout methods for a single line mainly include the shortest path method, the fitting passenger flow line method, and the search optimization algorithm\cite{10}. This model applies the algorithm of search optimization algorithm combined with the shortest path to solve: ① Firstly determine whether the rail transit stations at both ends of the bus connection interval obtained by Section 3.2.1 meet the requirements as the first and last stations of the bus, if not If it is satisfied, the interval is extended or shortened (the stations at both ends extend or shorten to no more than two stations upstream or downstream). ② Search for the \( K \) shortest path that satisfies the constraint between the orbital site and the first and last stations that meet the requirements. ③ Compare the objective function values of the \( K \) shortest paths of each of the first and last stations to find a path with the smallest objective function value. ④ Compare the paths with the smallest objective function values of the \( N \) first and last stations, and find the optimal path with the smallest objective function to get the final layout plan.

4. Examples

4.1. Example setting

There are 15 stations in Changchun Rail Transit Line 4, of which 6-7, 9-10, 11-12 stations have rail transit return lines. It is assumed that the rail transit stations 9-10 and 10-11 are interrupted by rail transit due to unexpected events.
4.2. Emergency vehicle dispatch

There are 4 bus emergency reserves in the city area, 1 represents the emergency reserve car point of Changchun station; 2 represents the preparation point of the Middle East market; 3 represents the satellite square emergency reserve car point; 4 represents the South Third Ring Road bus station.

According to the location of the accident, the vehicles are dispatched from the No. 2, No. 3, and No. 4 pick-up points. The survey obtained the passenger flow of the early peak in and out of the station, and calculated the OD passenger flow according to the system balance model[11], and finally determined the number of passenger flows affected by the passenger's selection behavior survey. Taking into account the travel delay time of passengers, it is assumed that the passengers from the fastest evacuation are the starting point, ignoring the impact of the dispatched emergency feeder bus on the regular bus. It is assumed that the rated passenger capacity of the bus is 100 and the rated passenger capacity is 0.9. The length of the emergency bus line is 7.1km. Assume that the bus runs at a speed of 25km/h on the road. The bus turnaround time is 2min, the bus stop time at each station is 0.5min, and the stop event at the end of the connection interval is 3min. The emergency bus connection scheme obtained by directly applying the passenger flow in section is scenario 1. The emergency bus transfer scheme obtained after considering the passenger's choice behavior is scenario 2. The connection scheme is shown in table 2.

Table 2. Comparison of bus emergency connecting scheme under passenger choice.

| Parameter                     | scenario 1 | scenario 2 |
|-------------------------------|------------|------------|
| Number of trips               | 21         | 9          |
| Feeder bus single running time (min) | 46.13     | 46.13     |
| Feeder bus capacity (vehicle) | 17         | 7          |

The operation time of each emergency reserve point to the connection station in schemes A and B is shown in table 3. The emergency feeder bus dispatching is divided into two schemes, and the vehicle is dispatched to the station 5, that is, the Jilin road station is the scheme A; the dispatched vehicle is to the station 13, that is, the south third ring station is the scheme B. The bus dispatch plan is shown in table 4. According to the algorithm of Section 3.1.2, scheme B in scenario 1 and 2 can dispatch emergency feeder bus in the shortest time. Therefore, scheme B is used to dispatch and connect the bus. The comparison shows that the cost of the connection is reduced after the passengers who do not choose rail transit are excluded.

Table 3. Operation time from reserve point to feeder station.

| Reserve Point | Option A: Site 5 | Option B: Site 13 |
|---------------|------------------|-------------------|
| 1 Changchun Station | 12.48min(2) | >15min |
| 2 Middle East market (10 veh) | 9.36min(1) | >15min |
| 3 Weixing Squares (6 veh) | >15min | 11.76min(2) |
| 4 South Third Ring (8 veh) | >15min | 0.55min(1) |

Table 4. Bus scheduling scheme.

| Reserve point | scenario 1(veh) | scenario 2(veh) |
|---------------|-----------------|-----------------|
|               | A-Site 5 | B-Site 13 | A-Site 5 | B-Site 13 |
| 1 Changchun Station | 7 | 0 | 0 | 0 |
| 2 Middle East market | 10 | 0 | 7 | 0 |
| 3 Weixing Squares | 0 | 9 | 0 | 0 |
| 4 South Third Ring | 0 | 8 | 0 | 7 |

4.3. Connection interval and line determination

The average station spacing of rail transit $L = 1.09km$, according to formula (2) and (3) and considering whether the rail transit station meets the conditions as the midpoint of the bus, determine the number of stations that need to use the emergency feeder bus to be transported upstream and downstream of the interruption interval are: $m_1 = 2$, $m_2 = 2$. According to the route layout model algorithm, it is
determined that the bus connection route is patrolled along Linhe Street Road, so the final emergency bus connection interval is shown in figure 3. The emergency feeder bus will be connected to the river in the connecting section along the Linhe Street by means of the station and the parking mode.

![Figure 3. Final feeder bus connection interval](image)

When an unexpected event occurs in the 9-10 and 10-11 intervals, the normal operation of the rail transit is interrupted, and the nearest turn-over line at both ends of the interruption interval is implemented, that is, the rail transit is carried out in the interval of site 1 to 7 and site 11 to 15. It is finally determined that the emergency connection interval of the bus is site 5 (Jilin Dalu Station) to site 13 (South Third Ring Road Station). In scenario 1, nine buses and eight buses need to be dispatched from emergency reserve point 3 and 4 in the shortest time, while in scenario 2, only seven buses need to be dispatched from emergency reserve point 3 to site 13 (South Third Ring Road Station). The feeder bus will implement two-way emergency connection operation from site 5 to 13.

5. Conclusion
The emergency bus connection scheduling scheme proposed in this paper considers passenger choice behavior, and the emergency bus connection scheduling considering passenger choice behavior saves the cost of bus dispatching, which is closer to the reality. The dynamic arrival and departure of urban rail transit and the corresponding behavior selection model should be established to further discuss the emergency connection problem. In the process of research, it is found that the scheduling model and bus line model interact with each other, and the unified model should be included in the following research for research and discussion.

References
[1] ARLOS, L.M., MARGARIDA, V.P. (1998) Search strategies for the feeder bus network design problem. European Journal of Operational Research, 106(2): 425-440.
[2] KUAN, S.N. (2006) Solving the feeder bus network design problem by genetic algorithms and ant colony optimization. Advances in Engineering Software, 37(6): 351-359.
[3] ZENG, A.Z., DURACH, C.F., FANG Y. (2012) Collaboration decisions on disruption recovery service in urban public tram systems. Transportation research part E: logistics and transportation review, 48(3): 578-590.
[4] DARMANIN, T., LIM, C., GAN, H. (2010) Public railway disruption recovery planning: a new recovery strategy for metro train Melbourne. Proc. 11th.
[5] KEPAPTSOGLOU, K.G., KARLAFTIS, M. (2010) The bus bridging problem in metro operations: conceptual framework, models and algorithms. Public Transport, 1(4): 275-297.
[6] TENG, J., XU, R.H. (2010) Public transport emergency response strategy in urban rail transit emergencies. Journal of railway science, 32(05): 13-17.
[7] LIANG, S.Z. (2014) Emergency bus transfer design of urban rail transit. Chang 'an University, Xi'an.
[8] LIU, B. (2017) Study on the plan of bus emergency linkage network under the interruption of urban rail train operation. Beijing Jiaotong University, Beijing.
[9] Fang, X.L. (2013) Research on the layout and optimization method of urban rail transit feeder bus lines. Southwest Jiaotong University, Chengdu.
[10] Zhao, X.H. (2006) Research on Coordination Transfer of Urban Rail Transit and Conventional Bus. Master's Thesis of Changsha University of Science and Technology, Changsha.
[11] Li, X.H, Wang, W., Chen, X.W. (2008) Road Traffic Planning. Nanjing: Southeast University Press, Nanjing.