Optimization Research of Emergency Resource on Rail Transit Allocation Location Considering Multiple Transport Modes

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Abstract. Rapid and effective emergency rescue is the key to reduce the loss of accidents after the occurrence of subway emergencies. Existing studies have not considered the difference between different demand stations and the use of multiple transportation modes for rescue. Reasonable allocation of subway emergency resources and transportation modes for rescue can improve rescue efficiency. In this paper, an emergency resource allocation model is established to minimize the generalized cost. The proposed model has two characteristics: one characteristic is to take passenger flow demand and historical accident data into consideration and quantify the passenger flow and frequency of station accidents to reflect the importance of different demand stations. Another characteristic is that the single rescue transportation mode is expanded into multiple transportation modes. Taking network of Beijing subway as an example, the model is applied and solved by CPLEX. When the actual data from 2013-2015 are substituted into the model, the solution result is compared with that of previous research model. The rescue time of this model considering multiple transport modes is lower than that of model considering single transport mode by 25.86%, and the rescue efficiency is improved. It concludes that the allocation model considering multiple transport mode can effectively reduce the time for rail transit when recovering from accidents.

1.Introduction
Urban rail transit lines and stations are an integral whole, with relatively closed operation space and concentrated passenger flow. After an emergency, the untimely rescue and disposal may lead to the concentration of passenger flow, resulting in the congestion of some stations or lines and low transportation efficiency, and even affecting the entire rail transit transportation network. The location of subway emergency resources allocation and the choice of rescue transportation mode are directly related to the timely and effective emergency rescue.

There are many researches on the allocation of emergency resources. In terms of emergency resource allocation location, Weber [1] selected the warehouse location with the minimum total distance from multiple customers through comparison. Sheu et al. [2] studied the allocation of emergency resources in major accidents and established a fuzzy optimization model aiming at minimizing the number of rescue facilities. Balcik et al. [3] constructed the maximum coverage model by considering the types and costs of emergency supplies. Moeini et al. [4] proposed a dynamic model for ambulance
configuration to minimize the number of uncovered demand points and the total transportation cost. Salman [5] et al. established the maximum coverage model to solve the location problem of emergency facilities. Liweijun et al. [6] studied the site location scheme of Beijing subway's emergency resources with the goal of emergency response time and the limitation of the number of emergency stations. Niexinlu [7] improved the particle cluster clustering algorithm to solve the number of cluster adaptively and calculated the minimum number and optimal location of emergency stations covering the whole network of Beijing subway. Lanzhen et al. [8] combined with historical accident data, and established a subway emergency maintenance personnel allocation model with the goal of minimizing rescue cost based on p-median model. Ranlianyue et al. [9] constructed a site location model for p-center emergency rescue station of urban rail transit based on the complex network theory. Under the constraint of limited emergency resources, Fengchun et al. [10] set the goal of maximizing the social value of emergency rescue and gave consideration of the fairness of distribution. In terms of emergency resource scheduling, ABOUNACE et al. [11] studied the multi-objective location-transportation problem of disaster response, and established a model to minimize the total transportation time, the number of distribution centers and the uncovered demand. Gehonglei et al. [12] established a two-stage stochastic planning model based on complex disaster scenarios. The first stage was the location inventory model, and the second stage was the emergency resources distribution model. Chengang et al. [13] established an optimization decision model for location of emergency logistics in an uncertain environment with multiple commodities, multiple modes of transportation, multiple stages and multiple objectives.

Most existing studies have some shortcomings: one is to consider a single transport mode for rescue, which may have limitations in emergency rescue. Secondly, different demands stations are treated equally and the probability of accidents in different stations is considered to be the same, which is inconsistent with the reality. Especially for the rail transit, the frequency of accidents in some areas is significantly higher than that in other areas.

The main contributions of this article are as follows: (1) This paper quantifies the passenger flow and frequency of station historical accidents to reflect the importance of different demand stations. The historical accident situation of the station can reflect the accident probability in the future to some extent. The passenger flow reflects the rescue demand of the station. (2) Single transport mode rescue is extended to the multiple transport mode rescue. Some accidents may lead to the interruption of rail transit operation, and other modes of transportation are adopted for emergency rescue.

2. Factors influencing the allocation location of emergency resources on rail transit

This chapter analyses the factors that affect the allocation of emergency resources on rail transit, mainly including the passenger flow of subway stations, the frequency of station accidents, and the transport modes for rescue.

2.1 The passenger flow of subway station

In urban rail transit system, passenger flow refers to the number of passengers passing through a certain section of the line in a certain direction in a unit time. According to the relevant provisions of the handling rules for operational accidents of Beijing subway operation CO., LTD., incidents that delay the operation of trains by 5 minutes or more are classified as rail transit operational accidents. According to the existing accident data, the study selected the accident data within the jurisdiction of Beijing subway operation Co., LTD from 2013 to 2015. In order to analyze the relationship between accidents and passenger flow, the passenger flow of different lines in the whole network and the frequency of historical accidents are statistically sorted out, as shown in figure 1. As can be seen from figure 1, the frequency of historical accidents in subway lines with large passenger flow is also relatively high. On the one hand, in the station with large passenger flow, there are more passengers and the load of subway equipment is large; On the other hand, after an accident occurs in a station with large passenger flow, the number of passengers affected is large, and the impact caused by the delay is also larger. In order to deal with emergencies as soon as possible and restore the operation of rail transit, considering the
difference of passenger flow in different stations, the allocation of emergency resources should be close to the stations with large passenger flow.

![Figure 1. Schematic diagram of line passenger flow and accident frequency.](image)

2.2 Frequency of station accidents

The frequency of station accidents refers to the ratio of the number of historical accidents in the station to the total number of accidents, which can reflect the probability of future accidents in the station to some extent, and is an important reflection of the actual demand of emergency rescue. In rail transit network, the stations prone to accidents are not evenly distributed. In order to shorten the average rescue time, it is necessary to consider the accident probability of different stations. The emergency station should be close to the station with high accident frequency.

2.3 Modes of transport for rescue

In order to recover from the accident as soon as possible and reduce losses, emergency resources should be transported to the accident site timely and rapidly. Due to equipment failure and other reasons, the subway may not be able to provide a complete route to transport emergency resources. Multiple transport modes can be considered. Different modes of transport have different characteristics, and the corresponding rescue time and cost are different. Cars are fast and flexible. When the traffic is unobstructed, the advantage of speed is obvious and the transportation cost is relatively high. The bus is susceptible to road traffic conditions, and the speed is slower. But the transport cost is lower.

3. Model

3.1 Assumptions

In order to facilitate the model establishment, the following assumptions are proposed:

1. The existing stations on the network all meet the requirements of setting up emergency stations and can store emergency resources.
2. This paper builds the model based on p-median model, which is to find a location scheme to minimize the total transportation distance (including transportation time or transportation cost) between the emergency point and the demand point when the number of emergency stations is determined or limited.
3. When rail transit is adopted as the mode of emergency rescue, it is assumed that the rail transit operation is not interrupted and emergency resources can be transported.
4. Emergency resources refer to the general term of all kinds of small resources needed in the rescue process in the event of an emergency. Rail transit, buses and cars can be used for transportation.

The definitions of the symbols used in this paper are shown in table 1.

| Symbol | Meaning |
|--------|---------|
| i      | Demand station index |
| j      | Emergency station index |
| k      | Mode of transportation index |
| m      | Number of emergency stations |
3.2 Allocation location model of emergency resources on rail transit

3.2.1 The importance of different demand stations
The importance of different stations in the whole network rescue is different. Quantize passenger flow and frequency of station accidents as a weight value to reflect the importance of different demand stations.

Statistics of accidents within the jurisdiction of Beijing subway operation CO., LTD from 2013 to 2015 are collected. The frequency of historical accidents in the station can reflect the probability of future accidents to some extent. On the basis of the same accident frequency, the station that once had a historical accident is multiplied by the corresponding magnification factor. In the stations with large passenger flow, more passengers are affected after the accident and the loss of delay is larger. Equation (1) is the weight of demand station that quantifies passenger flow and frequency of station accidents.

\[ E_i = \frac{1}{n} \times e^{P_i} \times Q_i \]

Where \( P_i \) is the frequency of station accidents according to historical accident data, \( e^{P_i} \) is the amplification factor, When \( P_i \neq 0 \), \( e^{P_i} > 1 \), frequency of station accidents is amplified.

3.2.2 The objective function
The objective function of the model is to minimize the generalized cost of the whole network rescue, which includes the total rescue time and the total transportation cost, as shown in equation (2).

\[ \min \sum_i \sum_j \sum_k (C_{kij}Z_{ij} + VOTx_{ij}Z_{ij}T_{ij}) \]

Where \( \sum_i \sum_j \sum_k (C_{kij}Z_{ij}) \) represents the total rescue transportation costs; \( \sum_i \sum_j \sum_k (x_{ij}Z_{ij}T_{ij}) \) represents the total emergency rescue time. Monetization of unit travel time is the value of travel time (VOT), and the concept of “value of time” is introduced. \( \sum_i \sum_j \sum_k (VOTx_{ij}Z_{ij}T_{ij}) \) represents the time cost of the total rescue time.

3.2.3 The constraints
(1) \( x_{ij}, y_{ij}, Z_{ij} \) are 0-1 decision variable, as shown in equation (3).

\[ x_{ij}, y_{ij}, Z_{ij} \in [0,1] \]

(2) A demand station can be rescued by at least one emergency station, as shown in equation (4).

\[ \sum_j x_{ij} \geq 1 \]
(3) The number of emergency stations is \( m \), as shown in equation (5).

\[
\sum y_j = m
\]

(4) The constraint between \( x_{ij} \) and \( y_j \). When \( j \) is the emergency station, \( y_j = 1 \), \( x_{ij} \) may be 0 or 1; when \( j \) is not an emergency station, \( y_j = 0 \), \( x_{ij} \) must be 0, as shown in equation (6).

\[
x_{ij} \leq y_j
\]

(5) The constraint between \( Z_{ij} \) and \( x_{ij} \). The corresponding emergency station chooses a certain mode of transport to rescue the demand station, and the choice of transport mode between different demand stations and the emergency station does not affect each other, as shown in equation (7).

\[
\sum Z_{ij} = x_{ij}
\]

In this paper, the decision variables of objective function are 0-1 variables, and the problem to be solved is integer programming problem. CPLEX software tool is selected to solve the model accurately. CPLEX is an optimization engine developed by ILOG, which can quickly solve large and complex problems. It can solve four basic problems such as linear programming problem, quadratic programming problem, constrained quadratic programming problem and second-order cone programming.

4. Case study
This paper takes the third company of Beijing subway operation as the research object. The existing accident data are from 2013 to 2015. Considering the construction and development of the line network, the network in 2015 is selected for study. The lines under the jurisdiction of the third company of Beijing subway operation include subway line 2, line 8, line 10 and line 13, with a total of 89 stations, as shown in figure 2. To facilitate the solution, the stations are numbered from 1 to 89, as shown in figure 3.

4.1 The value of the model parameters
According to Allocation location model of emergency resources on rail transit, the model parameters in case study are evaluated.

(1) Multiple modes of transport: three common modes of transport are subway, car and bus. (2) the weight of station: the frequency of accidents is counted from the statistics of the stations with accidents in Beijing subway from 2013 to 2015. The passenger flow of the station is obtained from the data of two weeks from December 19, 2015 to January 3, 2016. (3) Emergency rescue time and emergency rescue
cost: in the flat peak period, the time matrix and cost matrix of subway rescue are determined through 
AFC card data, and the time matrix and cost matrix of car and bus are determined through Baidu 
map. (4) The number of emergency stations is configured according to the proportion, and the number of 
emergency stations m is 24. (5) The value of time: calculate the value of time by the production 
method [14]. According to the data of the National Bureau of Statistics, VOT=53.25 yuan/hour.

4.2 The results
(1) Location result of emergency stations
CPLEX is used to solve the model, and the location results of 24 emergency stations are obtained 
and plotted in the line diagram, as shown in figure 4. The triangle represents the location of emergency 
stations in which emergency resources are deployed in this paper. It can be seen from the figure that the 
location of emergency stations is distributed in a good balance on the network, taking into account the 
demand of the entire line network.

(2) Rescue relationship
Each demand station has a corresponding emergency station for rescue. The rescue relationship 
solved by the model is shown in table 2:

| Emergency station | Demand station | Emergency station | Demand station | Emergency station | Demand station |
|-------------------|----------------|-------------------|----------------|-------------------|----------------|
| Chegongzhuang     | 2, 18, 19      | Xixiaokou         | 24, 26, 27, 28 | Dahongmen        | 60, 62         |
| Changchunjie      | 3, 6           | Zhichunli         | 35, 36, 39, 75, 79, 38, 80 | Jiaomendong | 61, 63, 64   |
| Hepingmen         | 4, 5, 7        | Jiandemen         | 29, 37, 40, 31, 81 | Niwa         | 65, 66, 67, 69, 71 |
| Beijing station   | 8, 10          | Beitucheng        | 30, 32, 41, 42, 43, 87, 84, 88 | Lianhuaqiao | 52, 68, 70, 72 |
| Jinguomen         | 9              | Nongyexhanlanguan | 45, 46, 47, 51 | Chedaogou      | 73, 74, 76, 77, 78 |
| Dongsishitiao     | 11, 13         | Jintaixizhao     | 48, 49, 50 | Shangdi         | 82             |
| Andingmen         | 12, 14, 16     | Panjiayuan        | 53, 54, 56, 58 | Huilongguan | 20, 83, 23 |
| Guloundajie       | 1, 15, 17, 33, 34, 89 | Chengshousi     | 55, 57, 59 | Huoying         | 21, 22, 25, 84, 85, 86 |

Figure 4. Diagram of emergency station location result.  
Figure 5. Comparison diagram of results between the two models.
(3) Rescue mode of transport

Cars are selected for emergency rescue in 66 stations, accounting for 74%. The subway is chosen to rescue 23 stations, accounting for 26%, while the bus is not chosen. The speed advantages of car are obvious, and the emergency response time is short. In the case of traffic congestion, the subway has an advantage over the car in time, and the transportation cost is lower. The speed of bus is slow, and bus is not suitable for emergency rescue.

(4) Comparison

Compared with the Lanzhen model, the objective function in this paper takes into account not only the rescue time but also the cost, and expands the single transport mode into multiple transport modes. The results of the rescue time and transportation cost solved by the two models are shown in table 3. As can be seen from table 3, when the number of emergency station is the same, the result of the model in this paper reduces the rescue time by 241min and 25.86%, because most of the rescue is done by cars with speed advantage. The transportation cost of car is higher than that of subway, but in case of emergency, time should be given priority to improve the efficiency of rescue.

| The objective function                                      | Rescue time /min | Rescue mode of transport | Rescue transportation cost/yuan |
|--------------------------------------------------------------|------------------|--------------------------|--------------------------------|
| This paper (generalized cost minimization considering multiple transport modes) | 691              | Subway, car, bus         | 1127                           |
| Lanzhen (minimum rescue time)                                | 932              | subway                   | 298                            |

In figure 5, triangles, circles and pentagons respectively represent the locations of emergency stations in this paper model, Lanzhen model and common stations of two models. The distribution areas of the emergency stations solved by the two models are not much different. Common stations have Beijing station, Xixiaokou, Zhichunli, Jintaixizhao, Dahongmen, Chedaogou and Huilongguan. The passenger flow and the number of historical accidents of these stations are large.

5. Conclusion

This paper analyses the relevant factors that affect the allocation of emergency resources on rail transit. Quantification of the passenger flow of station and frequency of station historical accidents indicates the importance of different demand stations. The single rescue transport mode is expanded into multiple transport modes. Considering the rescue time and cost, the optimization model of emergency resources allocation on rail transit is established with the objective of minimizing the generalized cost. The location of the emergency station, the rescue relationship and rescue transport mode are solved by taking the three company of Beijing subway as an example. The demand stations are rescued from emergency station with short distance, and 72% of the stations use car with fast speed to rescue. Compared with the model considering single transport mode, the model in this paper considering multiple transport modes has an increase in rescue transportation costs, but the rescue time has been reduced by 25.86%. It concludes that considering the passenger flow and the frequency of station historical accidents, the rescue time can be effectively reduced under multiple transport modes. This paper only studies a single emergency resource, but in reality a rescue often requires multiple resources. In the future, it is necessary to study the joint allocation of various emergency resources.

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