Research on Railway Emergency Rescue Path Selection Based on GIS

Zhaoping Tang\textsuperscript{1,*}, Shengyu Zhou\textsuperscript{1}, Biao Geng\textsuperscript{2} and Jianping Sun\textsuperscript{1}

\textsuperscript{1}School of Transportation and Logistics, East China Jiaotong University, Nanchang, China
\textsuperscript{2}Changsha Vehicle Depot, China Railway Guangzhou Group Co., Ltd., Changsha, China

*Corresponding author e-mail: tzp@ecjtu.edu.cn

Abstract. After the railway emergency, how to transport emergency rescue resources to the accident site in time and reduce all kinds of unnecessary losses caused by the accident is the primary purpose. Based on the theory of Geographic Information System (GIS), a calculation model of the shortest path was established. By using ArcMap software, the network data set based on railway network was analyzed and calculated, and the shortest path from emergency rescue point to accident point was solved and visualized. And supposed that an emergency happened in the area under the jurisdiction of Nanchang Railway Administration, and made an empirical analysis of it. It provides reference for the selection of emergency rescue path after railway emergencies.

1. Introduction

With the gradual increase of the density of the railway network, which poses greater challenges to the railway transportation safety. If the emergency rescue cannot be carried out in a timely manner after the occurrence of an emergency, the impact of the emergency may be further expanded. At present, the rescue work of railway emergencies is still experience-oriented, and the related systematic theoretical research is still insufficient. How to select the emergency rescue route quickly is an important guarantee for the emergency rescue resources to arrive at the accident site timely.

Scholars at home and abroad have studied such problems from different directions. In terms of the application of geographic information system, Lira W P assisted railway safety management with visual analysis system and provided help for safety engineers to make decisions [1]. Hu Z et al. design the catastrophic emergency rescue system. It can integrate multi-source data for synergy analysis [2]. Liu et al. developed the emergency auxiliary decision-making system with the help of big data technology to provide technical reference for emergency decision-making [3]. In terms of scheduling path selection. Tian Z et al. established an optimization model considered both ending time of rescue and dispatching cost of equipment and designed a two-stage heuristic algorithm that considers the end time of rescue first [4]. Wu X analyzed the shortest path of production, wholesale and sales place through WebGIS [5]. Zhou et al. calculated the optimal route of emergency rescue vehicles and the optimal emergency material distribution scheme by using GIS and mobile positioning technology [6]. Jie C et al. proposed an emergency rescue scheduling model with the minimum rescue time as the first objective function, the minimum delay cost as the second objective function, and the maximum life-saving utility as the last...
objective function [7]. Zeng ZC introduced WebGIS software in logistics distribution, optimized the target path through genetic algorithm, and presented the result of path selection in the vehicle information system [8]. Xu et al. designed an optimization design scheme integrating gradient scheduling system into GIS, providing a new direction for the optimization of GIS cloud platform [9]. Sterk presented multiple improvements and novel features aimed at emergency response to be improved both the speed and the reliability of emergency response [10].

In general, the application of geographic information technology in railway system is very common at home and abroad. However, there are few studies on how to use GIS platform to provide assistance for emergency rescue work. In this paper, based on GIS theory and ArcGIS software, firstly created a traffic network data set. After the accident, in order to transport the emergency rescue resources to the accident point as soon as possible, the shortest path from the rescue point to the accident point was analyzed and to be visualized in ArcGIS.

2. Shortest path model
The shortest path problem, that is, in a composed of nodes and the path to calculate the shortest path between two nodes in the graph. There may be multiple paths between one node (starting point) and the other node (ending point) in the graph. In all can pass the path of seeking out a path to meet the conditions, the sum of all the path length on this path to a minimum.

2.1. Network diagram
Based on the characteristics of the emergency rescue route, the whole road network traffic is abstracted into a directed weight map $G = (U, E, C)$. In the formula: $U = \{v_1, v_2, \ldots, v_n\}$ is the aggregate of nodes, $v_i, v_j$ is any two points in the map, The road $(v_i, v_j)$ in the map has the weight $l_{ij}$ ($l_{ij} = \infty$ indicates that there is no connection between $v_i$ and $v_j$). $e_{ij}$ represents a path from $v_i$ to $v_j$, $E$ is the path set, and $C$ is the weight set of the path.

2.2. Path constraint
For the constraint of railway emergency rescue shortest path problem, it is assumed that:

- There is only one definite starting and ending point for the transportation of emergency rescue resources.
- From the starting point to the final destination, choose the only route as the rescue route.
- After entering any node($v_j$) in the map, it must proceed from that node and shall not terminate or disappear.

2.3. Model establishment
Combining with practical problems in the transportation process, the following mathematical model is established:

$$
\begin{align*}
min L &= \sum x_{ij} l_{ij} \\
l_{ij} &= (1 - y_{ij})M + e_{ij} \\
x_{ij} &\leq y_{ij} \\
\text{subject to} \quad &x_{ij}, y_{ij} \in \{0,1\} \\
&v_i, v_j \in U \\
&(v_i, v_j) \in E
\end{align*}
$$

(1)
In the model, \( l_{ij} = (1 - y_{ij}) M + e_i \) represents the weight of the path between any two points, \( M \) is any large positive number. \( x_{ij} \in \{0,1\} \), \( x_{ij} = 1 \) indicates that the path is selected, otherwise \( x_{ij} = 0 \), \( y_{ij} \in \{0,1\} \), \( y_{ij} = 1 \) indicating that the road is passable, when the road is damaged \( y_{ij} = 0 \).

2.4. Dijkstra algorithm

Dijkstra algorithm is considered to be the best algorithm to solve the problem when the weight is greater than 0. Its main feature is the idea of breadth-first search, that is, to expand layer by layer from the starting point to the outer layer until finally reaching the end point.

Its basic idea is the result of graph theory, by setting a representation for the weighted adjacency matrix \( C \) to describe with \( N \) nodes weighted directed graph \( G = (U,E,C) \). The weight of arc \((v_i,v_j)\) is denoted by \( l_{ij} \). If from \( v_i \) to \( v_j \) is not passable, then \( l_{ij} = \infty \) as required, an auxiliary vector \( Dist[i] \) is introduced and set \( v_0 \) as the starting point. Any \( Dist[i] \) represents the minimum value from the starting node to all the ending points \( v_j \), set the initial value as \( Dist[i] = l_{ij}, v_j \in U \). Among it, \( U \) is the set of nodes. Set \( S \) as the set of all sub-paths in the shortest path searched, and the initial value is \( S = \{v_0\} \). Then, the shortest path weight from the starting point to any other node in the graph is \( Dist[i] = l_{ij}, v_j \in U \), and the specific solving steps are as follows:

Choose \( v_j \), make \( D[j] = \min \{D[i] | v_i \in U - S \} \). \( v_j \) is set as the end point, the shortest path is calculated under the constraint conditions, and then merge the obtained \( v_j \) into set \( S \), which is expressed as \( S = S \cup \{v_j\} \).

Calculate the shortest path length from the starting point \( v_0 \) to the arbitrary selected vertex \( v_i \) in the new set \( U - S \). If the found path vector has the following relationship: \( D[j] + l_{jk} < D[k] \), then step 3).

(3) Replace path weight \( Dist[k] \) with \( Dist[k] = Dist[j] + l_{jk} \); Repeat steps (2) and (3) \( N-1 \) times, to obtain the shortest path from \( v_0 \) to any node in the graph.

3. Network analysis

Based on the characteristics of railway emergency rescue——timeliness and urgency, the primary purpose of emergency rescue work is how to make the shortest rescue time. And the choice of transportation path directly determines the transportation time of emergency resources. Through the Network analyst module in ArcMap, the shortest path between any two points can be solved and analyzed.

Firstly, ArcCatalog 10.2 software was used to create the traffic network data set. This paper took the railway lines, railway stations and rescue bases under the jurisdiction of Nanchang railway bureau (including Jiangxi and Fujian provinces) as the main data to construct a traffic network data set.

Determine the target point through the network location tool created in ArcMap, and decide whether to add obstacles according to actual situation. Based on the solution model of shortest path, the weight of all feasible routes between two target points is calculated. Where the path with the minimum total weight is the optimal choice.

4. The empirical analysis

Nanchang railway bureau covers the whole Jiangxi and Fujian provinces and parts of Hunan and Hubei provinces, with a total operating mileage more than 7,700 kilometers. Nanchang railway bureau has 14 emergency rescue bases. Each base is equipped with a special rescue train and related emergency rescue resources.
Taking Nanchang railway bureau as an example. This paper assumed that a major emergency occurs somewhere between Zixi railway station and Guangze railway station. Use $A_1$ to $A_{14}$ to represent the emergency bases of Pingxiang, Xinyu, Xiangtang, Yingtan, Shangrao, Jingdezhen, Jiujiang, Ganzhou, Fuzhou, Xiamen, Zhangping, Yongan, Laizhou and Shaowu.

From 14 rescue bases, Dijkstra algorithm was used to calculate the shortest path model which established above. According to the actual situation, obstacle points can be added, That is, assign the value of $y_{ij}$ in the model. When there is an obstacle, take $y_{ij} = 0$ indicating that the road section where the obstacle point is located is impassable.

Under the condition that no obstacles are set, the shortest path and path length from each emergency base to the accident point were calculated, as shown in table 1. The visualization results on the map are shown in figure 1.

![Figure 1. Analysis of the shortest path for rescue in each emergency rescue base](image)

**Table 1.** Length of rescue route from each emergency rescue base to the accident point (unit: m)

|       | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
|-------|-------|-------|-------|-------|-------|-------|-------|
| $l$   | 465369| 341802| 214684| 99756 | 205955| 252863| 373194|
| $A_1$ | $A_8$ | $A_9$ | $A_{10}$| $A_{11}$| $A_{12}$| $A_{13}$| $A_{14}$|
| $l$   | 593441| 367883| 585853| 407318| 303423| 220267| 44637 |

According to the speed $v$ of the emergency rescue train (set its average running speed as 75km/h) and the shortest distance $l$ calculated, the transportation time $t_l$ from each emergency rescue base to the accident point can be obtained. The total time required for rescue is the sum of the response time of the
rescue base (take the response time $t_r$ of the emergency base as 0.5 hours) and the transportation time $t_t$ of the accident point to the rescue base. So total time $t = t_r + t_t$. The calculation results are shown in table 2.

| $A_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
|-------|-------|-------|-------|-------|-------|-------|-------|
| $t_i$ | 6.70492 | 5.05736 | 3.36245 | 1.83008 | 3.24607 | 3.87151 | 5.47592 |
| $t_i$ | 8.41254 | 5.40511 | 8.31137 | 5.9309 | 4.54564 | 3.43689 | 1.09536 |

The calculation results are shown in table 2.

| $A_i$ | $A_8$ | $A_9$ | $A_{10}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ | $A_{14}$ |
|-------|-------|-------|----------|----------|----------|----------|----------|
| $t_i$ | 8.41254 | 5.40511 | 8.31137 | 5.9309 | 4.54564 | 3.43689 | 1.09536 |

The shortest rescue path from each rescue base within the jurisdiction to the accident point was obtained. Take the emergency rescue base of Ganzhou city as an example.

When the barrier-free point exists, the shortest rescue route is as shown in figure 1 above, the one from the point 1 to the accident point. The railway stations passing through mainly include Xingguo, Jian, Fengcheng and Zixi, etc. The length of the route is 593,441 meters, lasting about 6.7 hours.

It is assumed that Jian station is impassable for some reasons. The shortest rescue route is as shown in figure 2 below. The main railway stations passing through are Yudu, Ruijin, Shaowu and Guangze, etc. The length of the route is 716,932 meters, which takes about 10 hours.

5. Conclusion
Based on the theory of geographic information system, taking Nanchang railway bureau as an example, it assumed that a railway emergency occurred in the jurisdiction. Through the network analyst module, direct access to the shortest path between any two points or the shortest path when there is a place is
impassable due to special reasons. The solution results are presented in the network traffic data set of Nanchang railway bureau. Provide basis and decision support for emergency resource allocation. How to carry out the rescue work efficiently after the railway emergencies involves many factors. With the help of GIS platform, it is still limited to the analysis and display of rescue path. Research only takes ordinary railway as the object, without considering the situation of high-speed railway and highway network. For emergency rescue, the realistic rescue route selection is more complicated, and the joint rescue of highway and railway is a field worth expanding.

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