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Research on Emergency Evacuation Path Based on Improved Floyd's Algorithm

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Abstract: Abstract-As an important link of natural gas gathering and transportation system, leakage of natural gas station may cause serious hydrogen sulfide poisoning accidents. Especially under the condition of complex terrain, it is difficult to select the emergency path. The emergency evacuation path of the station was optimized based on the improved Floyd algorithm. Considering the evacuation characteristics of the leakage accident of the mountain station, the multi-objective evacuation model was established by considering the evacuation path safety, path slope and path reliability. The improved Floyd algorithm was brought into the case study. Through the selection of regional emergency refuge points, the topology of road network was established and solved by the algorithm, and the optimal evacuation route in the region was obtained. Finally, a scientific and perfect evacuation strategy for each residential area under the accident was formed.

Keywords: Gas Station; Emergency Evacuation; Improved Floyd Algorithm

1. Introduction

In the face of the increasing demand for natural gas, the development of high sulfur-bearing gas fields is increasing year by year, in addition to the development of conventional natural gas resources. However, hydrogen sulfide in sulfur-bearing gas fields is a colorless, heavier-than-air, highly toxic gas that seriously affects the safety of the surrounding residents. In order to minimize casualties and property damage from such leaks, it is especially important to develop a reasonable emergency evacuation path. Emergency evacuation is an important part of emergency management, and its strategy development is a reflection of the level of emergency response capability and an important means to protect people from accidents[1-2].

Overseas research on emergency evacuation started earlier, beginning in the 1960s. Initially, it focused on analyzing personnel evacuation behavior, leading to the derivation of various evacuation formula models. Later, with the development of computer technology, evacuation simulation research via this technology became the mainstream. Currently, for large - area emergency evacuation under emergencies, domestic and foreign scholars' research hotspots are on optimizing evacuation route decisions by setting targets, adding constraints, and globally searching for paths to find the best routes. Many domestic scholars have applied algorithm models to evacuation path planning, but most research is on indoor evacuation in large buildings and urban traffic road evacuation, with less on mountainous area evacuation. Since most natural gas stations in China are in mountainous areas with complex terrain, developing effective evacuation strategies and route planning can significantly shorten evacuation and rescue time, which is important for improving emergency response capabilities.

In this paper, we will collect high-precision geographic information in the emergency evacuation area by means of UAV aerial photography and collect information on the distribution of human settlements in the area through field research for mountainous station leakage accidents. Combining with the characteristics of hydrogen sulfide diffusion in mountainous areas, a mathematical model is established by considering the indicators of path safety, path slope and path reliability, and the optimal evacuation path for each residential point under the accident is solved with the goal of the shortest evacuation path..

2. Floyd Algorithm Model Improvement

The Floyd algorithm, also known as the interpolation method, is an algorithm that uses dynamic planning ideas to solve large area, multi-node evacuation road networks [3].The Floyd algorithm uses triple-loop search for road network nodes, which has a compact structure and is widely used in solving the shortest path model between two points. Therefore, with reference to the characteristics of wide evacuation range and many branch road nodes in mountainous areas, Floyd algorithm is chosen as the path planning algorithm for emergency evacuation in mountainous areas.

Floyd algorithm is to use the idea of dynamic planning, based on this initial weight matrix for iterative calculation. The idea is that by triple cyclic search of the path, the iterations are continuously updated until the shortest path between two points is found, and the distance matrix and routing matrix are thus updated [4-6].The iteration rules of the Floyd algorithm are shown in Equation 1. By searching the intermediate nodes between the starting and ending nodes, their shortest distance is constantly compared with the transit distance, and if the sum of the transit distances is less than the current shortest distance, the path update is successfully achieved by.

$$d(i,k)+d(k,j)<d(i,j) \tag{1}$$

where $d(i,k)+d(k,j)$ denotes the node i,j the distance from node k in transit, $d(i,j)$ denotes the shortest distance between nodes i, j. If the former is less than the latter, the shortest path is updated at this point, i.e $d(i,j)=d(i,k)+d(k,j)$. In addition, in order to record the shortest path, the elements of the routing matrix are updated accordingly, i.e. $r(i,j)=r(i,k)$.

2.1 Floyd Algorithm Model Improvement

When evacuating near a leak at a station, the optimal path isn't always the shortest. Toxic gas spreads downwind, so evacuees must avoid concentrated gas areas. Stations are often in rugged mountains, complicating evacuation: slopes reduce walking speed, and narrow paths risk congestion, hindering the process.

For evacuation in mountainous stations during accidents, factors like path slope, safety, and congestion significantly impact outcomes. This paper addresses toxic gas leakage by quantifying these indices—safety, slope, and capacity—and incorporating them with evacuation distance as inputs into Floyd's algorithm to enhance it[7].

Based on the above analysis, the concept of equivalent coefficients is also introduced for determining the equivalent length value of the path. Each of the equivalence coefficients is independent of each other and together affect the determination of the equivalent length [8].

First, three mutually independent influence indicators in the calculation of the equivalent length are determined, namely, the path safety influence factor $f_1(S)$, the path slope influence factor $f_2(\theta)$, and the path reliability influence factor $f_3(P)$. The evacuation equivalent length is obtained by dividing the path geometric length with each factor and expressed by the formula as follows.

$$d_{ij} = \frac{l_{ij}}{f_1(S)\cdot f_2(\theta)\cdot f_3(P)} \tag{2}$$

where d_{ij} denotes the geometric length of the path ij in m.

Given the parameter index values on each path, the equivalent length of any path route can be obtained. Therefore, the optimization objective changes from a single path length shortest model to a multi-objective optimization model that includes path safety influence coefficient, path slope influence coefficient and path reliability influence coefficient.

According to the above description, the optimized mathematical model can be established:

$$\min D(L,S,\theta,P)=\sum_{i}^{n}\sum_{j}^{n} d_{ij}x_{ij} \tag{3}$$

$$x_{ij}=\begin{cases}1, & \text{If the path contains a path between i, j}\\ 0, & \text{If the path does not contain a path between i, j}\end{cases} \tag{4}$$

2.2 Path Safety Factor Indicators

Evacuation path safety refers to the ability of personnel in the evacuation process from the toxic effects of the gas leak. Studies have shown that when evacuees walk in a toxic environment, toxic gases can in some cases affect evacuees psychologically and physiologically thus hindering the evacuation process. Since residents need to go through steps such as detector alarm, personnel response, and accident notification before carrying out evacuation actions, this study assumes that personnel start evacuation 300 s after the occurrence of the leak, and quantifies the evacuation road safety index by assessing the hydrogen sulfide concentration on each path 300 s after the occurrence of the leak [9], with reference to previous drills at the station. The higher hydrogen sulfide concentration in the area where the evacuation path is located indicates that the path is less safe.

When the percentage of hydrogen sulfide concentration is lower than 0.002 (i.e., 20 ppm), it has no effect on the escape speed of personnel in a short period of time; when the percentage of hydrogen sulfide concentration is higher than 0.01 (i.e., 100 ppm), the evacuation of escape personnel will be significantly affected; when the percentage of hydrogen sulfide concentration is higher than 0.03 (i.e., 300 ppm), personnel will lose the ability to escape. Based on this, with reference to the indicator thresholds of relevant papers[10], the formula for determining the impact indicators of toxic gases is given as:

$$f_2(S)=\begin{cases}1 & S\le 0.002\\ -12500S^2+50S+0.95 & 0.002<S\le 0.01\\ -475S^2+9.5S+0.1525 & 0.01<S\le 0.03\\ 0.01 & S>0.03\end{cases} \quad (5)$$

Where: S indicates the concentration of hydrogen sulfide in the evacuation area (%).

2.3 Path Reliability Factor Index

Evacuation path reliability reflects the path's ability to support continuous, uncongested evacuation without unexpected interruptions. The primary factor influencing reliability is road capacity, followed by road conditions. A path with a smooth surface, high capacity, and good conditions is generally considered highly reliable, ensuring a high probability of successful evacuation.

However, a path with good surface condition and high reliability may become congested due to widespread use, reducing its reliability. Thus, path accommodating capacity is key to characterizing path reliability.

Below a critical density, evacuation speed remains maximal. Exceeding this density reduces speed, eventually reaching a limit density where congestion halts movement[11].

Referring to the relevant papers, the crowd movement speed and the crowd density can be expressed by the following formula[12]:

$$v_i=v_{max}\left[0.797-0.313\ln(\rho)-0.0138\rho\right],\quad \rho_c\le\rho<\rho_{max} \quad (6)$$

The paper obtained through experimental studies that the critical density of crowd movement is 1.18 persons/m^2 and the limiting density is 6 persons/m^2, from which the path reliability coefficient is taken as the following segmental function:

$$f_3(P)=\begin{cases}1 & \rho\le 1.18\\ 0.797-0.313\ln(\rho)-0.0138\rho & 1.18<\rho\le 6.0\\ 0.01 & \rho>6.0\end{cases} \quad (7)$$

Where: ρ indicates the density of human flow in the evacuation area (person/m^2).

3. Example Analysis

Yuanba Gas Field, located in Guangyuan and Nanchong cities of Sichuan Province, is characterized by 'one over, three highs, and five complexities' -a term describing its unique geological features. This makes its development particularly challenging and high-risk, with an average hydrogen sulfide content of 5.53%. Sichuan City, and the nearby area is a shallow hilly terrain, mainly composed of slopes and residual clayey soils. The surrounding topography and population distribution are shown in Figure 1.

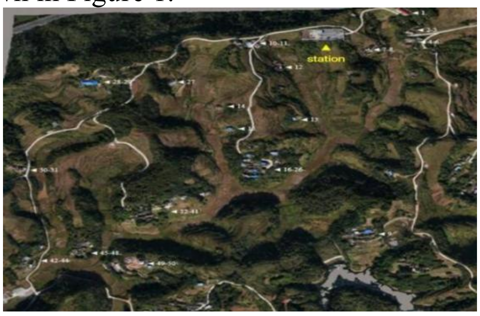

Figure 1. Distribution of Human Settlements in the Evacuation Area

3.1 Selection of Emergency Evacuation Points

Two key factors for selecting emergency shelter sites are wind direction and altitude[13]. Meteorological data shows the site's predominant wind direction is northeast (75% frequency), followed by east (20%), with other directions at 5%. For leakage accidents, evacuation points should be upwind or crosswind to minimize exposure. Hydrogen sulfide dispersion patterns must be considered. Additionally, practical factors include evacuation distance—shorter distances reduce evacuation time—and site accessibility, ensuring open areas for easy evacuation and potential secondary relocation if needed[14].

Considering the above factors, two emergency evacuation points for the evacuation of residents were delineated. Firstly, through the simulation, it was obtained that no hydrogen sulfide gas gathered at these two points regardless of the wind direction of northeast or east wind; through the 3D model height, it was found that the station elevation was 609.34 m, and the elevation of the two points of 1.2 were 616.57 m and 616.01 m respectively, which were higher than the station elevation; in addition, considering the evacuation distance of residents and the influence of wind direction, two emergency evacuation points were selected vertically on both sides of the wind direction. In addition, considering the evacuation distance and wind direction, an emergency evacuation site was selected on both sides of the wind direction, located on the west and southeast sides of the station, respectively, to facilitate temporary evacuation. The selection of emergency evacuation points is shown in Figure 2 with yellow markings.

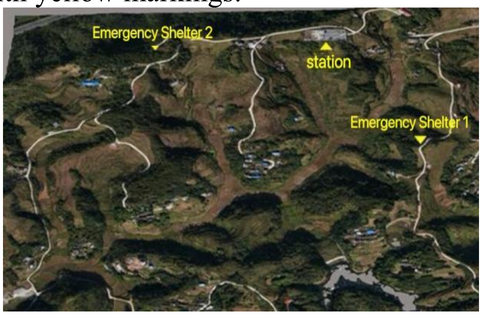

Figure 2. Location Selection of Emergency Refuge Points

3.2 Road Network Topology Modeling

The actual road includes not only passable paths but also other information elements that are not relevant for evacuation, so the actual road network must be simplified to retain only the paths that are available for evacuation within the evacuation area [15]. In order to carry out evacuation studies, a graph-theoretic approach can be used to transform the actual road network into a computer language recognizable by the program [16].

A graph theoretic model is a simple and straightforward model that visually reflects the logical relationships between the elements of the graph. When using graph theory for road network simplification, other information elements that are not relevant for evacuation can be discarded, but care should be taken to maintain the accuracy of the model and avoid over-simplification[17]. Thus, when transforming the actual road network, it is simplified to a road network topology containing basic data, and the three elements of nodes, arcs, and weights, representing transit points, evacuation paths, and evacuation distances, respectively, as shown in Figure 3. Where V represents the node, $V = \{V_i \mid i = 1, 2, 3 \cdots n\}$ E represents the path, $E = \{E_i \mid i = 1, 2, 3 \cdots m\}$; V and E topology form the topology $G, G = (V, E)$.

In this paper, when considering the establishment of the road network topology, the emergency information elements, such as the distribution of human settlements, temporary emergency shelter assembly points, the scope of the accident area, and existing evacuation routes, are integrated and incorporated. In addition, the path elements that have little relationship with the emergency evacuation of this accident, such as some bypasses or dead-end roads that are not related to evacuation, are discarded.

The process of converting the actual road network into the basic data road network topology is shown in Figure 3. By simplifying the road network, a total of 19 evacuation nodes and 32 segments of arc were delineated and their distances were measured separately, and their information records are shown in Table 1.

Through the equivalence factor calculation method, different equivalence factor values under each path are obtained, and finally the equivalence length of each path is obtained, and the information of each path is shown in Table 1.

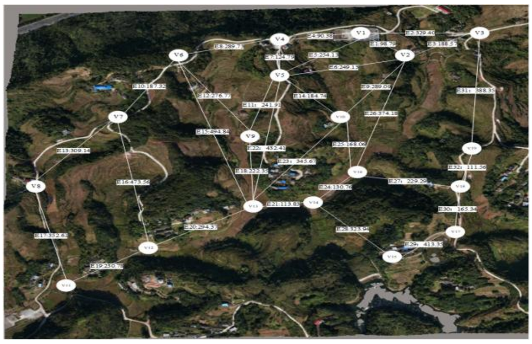

Figure 3. Topological Model of the Evacuation area Road Network

The Floyd algorithm program consists of three parts: the matrix information input code, the algorithm code, and the path output code. The algorithm code is the core, which contains the triple loop structure of the algorithm and the iteration rules for paths and nodes. The Floyd algorithm code also needs to store the initial information through the matrix information input code. The matrix information input code includes the initial routing matrix information input and the loop count setting, which is obtained according to the matrix construction principle of the previous section and modified by the above-mentioned factors, while the loop count represents the number of searches, which takes the value of the number of nodes [18].

The road network matrix information is brought into matlab programming, and after triple loops of initial node, terminal node and intermediate node in matlab programming, i.e., three global searches are performed, and finally the routing matrix R under path optimization is obtained after several iterations of information. The optimal evacuation path for each evacuation point, as shown in Table 2.

Table 1. Equivalent Coefficient and Equivalent Length of Evacuation Path

Arc section	Nodes	geometric distance(m)	$f_1(S)$	$f_2(\theta)$	$f_3(P)$	Equivalent length
E1	V1-V2	98.79	0.8	0.94	0.95	138.28
E2	V1-V3	329.40	1	0.98	1	336.12
E3	V2-V3	188.57	0.94	0.88	0.95	239.95
E4	V1-V4	90.38	0.84	0.97	1	110.92
E5	V1-V5	254.13	0.01	0.83	0.95	32229.54
E6	V2-V5	249.13	0.01	0.77	0.95	34057.41
E7	V4-V5	124.79	0.14	0.99	1	900.36
E8	V4-V6	289.73	1	0.98	1	295.64
E9	V2-V10	289.09	0.54	0.92	0.95	612.53
E15	V6-V13	494.84	0.82	0.97	1	622.12
E16	V7-V12	473.56	1	0.92	1	514.73
E17	V8-V11	352.61	1	0.98	1	359.80
E18	V9-V13	222.35	0.67	0.98	0.95	356.46
E19	V11-V12	230.78	1	0.99	0.95	245.38
E20	V12-V13	294.37	0.93	0.99	0.95	336.55
E21	V13-V14	113.83	0.87	0.99	0.95	139.11
E22	V5-V13	432.41	0.27	0.96	1	1668.24
E23	V10-V13	345.67	0.51	0.95	0.95	751.70
E24	V14-V16	130.76	0.97	0.97	0.95	146.28
E25	V10-V16	168.06	0.87	0.88	0.95	231.06
E26	V2-V16	374.18	0.96	0.97	0.95	422.97
E27	V16-V18	229.29	1	0.85	0.95	283.95
E28	V14-V15	323.94	1	0.90	0.95	378.87
E29	V15-V17	413.35	1	0.92	1	449.29
E30	V17-V18	165.34	1	0.97	1	170.45
E31	V3-V19	388.35	1	0.96	1	404.53
E32	V18-V19	111.56	1	0.96	1	116.20

Table 2. The Optimal Evacuation Route for Evacuees

Nodes	Account Number	Evacuation path
V1	Station Staff	V1→V4→V6
V3	1-6	V3→V19
V2	7-8	V2→V3→V19
V15	9	V15→V17→V18→V19
V4	10-12	V4→V6
V10	13	V10→V16→V18→V19
V9	14、15	V9→V6
V13	16-26	V13→V14→V16→V18→V19
V6	27	V6
V8	30-31	V8→V7→V6
V12	32-41	V12→V7→V6
V11	42-50	V11→V8→V7→V6

4. Conclusion

Aiming at the characteristics of emergency evacuation of mountainous stations for leakage accidents, the multi-objective model was established by incorporating index factors such as path safety, path slope and path reliability, and the model improvement of Floyd algorithm was completed. Based on the high-precision geographic information, the evacuation road network topology model was established. Finally, the model was brought into the program to solve the calculation, and the specific evacuation route for the residents around the station under the accident was obtained iteratively, which realized the optimization of evacuation strategy and provided an important reference for shortening the evacuation time of the surrounding residents and improving the emergency response capability of the station.

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