An Enhanced Routing Method with Dijkstra Algorithm and AHP Analysis in GIS-based Emergency Plan

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***Abstract*—Emergency response planning is a critical aspect of managing disaster situations effectively. Geographic Information Systems (GIS) are increasingly utilized to enhance emergency routing methodologies. This paper proposes an enhanced routing method combining Dijkstra's algorithm with the Analytic Hierarchy Process (AHP) in a GIS framework for emergency planning. The proposed method aims to optimize route selection and decision-making processes in emergency situations.**

Keywords—Emergency Routing, Dijkstra Algorithm, Analytic Hierarchy Process (AHP), Geographic Information Systems (GIS), Decision Support Systems.

I. Introduction

In recent years, the need for efficient emergency response systems has gained prominence due to the increasing frequency of natural and man-made disasters. Geographic Information Systems (GIS) have proven to be valuable tools for managing and analyzing spatial data related to emergency planning. Among the various routing algorithms, Dijkstra's algorithm is widely used for finding the shortest path in a graph, while the Analytic Hierarchy Process (AHP) is a decision-making framework that can help in evaluating multiple criteria.

In emergency fire response, the primary challenge is determining the quickest route to the accident scene amid complex conditions. Traditional shortest path algorithms like Dijkstra's have been widely used, including in GIS-based emergency systems. Dijkstra's algorithm calculates the shortest path between two nodes based on distance alone, neglecting other critical factors such as traffic volume, road width, and junctions.

However, these factors can significantly impact response times and the effectiveness of the emergency response. To address these limitations, integrating GIS with Analytic Hierarchy Process (AHP) offers a more comprehensive approach. This enhanced Dijkstra algorithm considers multiple criteria beyond mere distance, incorporating real-world road conditions and logistical factors.

By combining AHP with GIS, this method provides a more nuanced routing solution for fire forces, accounting for various impediments and improving emergency response efficiency. This approach represents a significant advancement over traditional models, allowing for more effective and practical emergency planning.

This paper integrates Dijkstra’s algorithm with AHP in a GIS-based environment to enhance routing methods for emergency planning. The proposed approach leverages the strengths of both techniques to provide more reliable and efficient routing solutions during emergencies.

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II. METHODOLOGY

A.Dijkstra's Algorithm

Dijkstra’s algorithm is employed to find the shortest path between nodes in a graph. It operates by iteratively selecting the node with the smallest known distance, updating distances to adjacent nodes, and repeating until the shortest path is found.

B.Analytic Hierarchy Process (AHP)

The AHP is used to evaluate and prioritize multiple criteria in decision-making processes. It involves decomposing a complex problem into a hierarchy, comparing criteria pairwise, and deriving weights to reflect their relative importance.

C. *GIS Integration*

The GIS framework provides spatial data necessary for implementing the routing algorithms. It includes layers for roads, obstacles, and hazard zones, which are essential for accurate route analysis and planning.

III. Proposed Enhanced Routing Method

The proposed method integrates Dijkstra's algorithm with AHP as follows:

1. Data Preparation: Collect and prepare spatial data layers in GIS, including road networks, hazard zones, and infrastructure.
2. AHP Analysis: Define criteria for route selection (e.g., distance, safety, accessibility). Use AHP to weight these criteria based on their importance in emergency scenarios.
3. Routing Calculation: Apply Dijkstra’s algorithm to calculate the shortest path considering the weighted criteria from AHP.
4. Route Evaluation: Evaluate the proposed routes using GIS tools to ensure they meet emergency response requirements and constraints.

IV. Enhanced Dijkstra with AHP Analysis

A.Classical Dijkstra Algorithm

Dijkstra's algorithm, introduced by Edsger Dijkstra in 1959, finds the shortest path in a graph with nonnegative edge costs. It works by iteratively improving the shortest path estimates from a starting node to all other nodes, marking nodes as visited once their shortest path is determined.

B.Concept of Enhanced Dijkstra Algorithm with AHP in GIS

Traditional Dijkstra's algorithm focuses on distance but can be limited in real-world scenarios due to factors like traffic volume and road conditions. To address this, the Enhanced Dijkstra algorithm incorporates AHP, which considers multiple criteria to optimize travel time rather than just distance.

C. *Impedance Factor Selection*

Selection of evaluation criteria involves identifying key factors that affect route efficiency, such as road type, traffic volume, and junction density. AHP helps quantify the importance of these factors based on input from experienced firemen and existing research.

D.AHP Processing

The AHP process involves:

The Analytic Hierarchy Process (AHP) is used to enhance decision-making by structuring problems into a hierarchy and calculating priorities for various criteria.

i. Model the Problem as a Hierarchy:

Break down the problem into a hierarchy with the goal,alternatives, and criteria for evaluation. The hierarchy helps clarify the problem and its context, leading to a more structured decision-making process.

ii. Pairwise Comparison:

- Compare elements in the hierarchy using pairwise comparisons to determine their relative importance.
- Use a scale (Table I) to quantify the importance of one element over another.
- Compute comparison ratios and priorities using the geometric mean method.

$$r_i = \prod_{j=1}^{n} (a_{ij})^{1/n}$$

$$w_i = \frac{r_i}{\sum_j r_j} \qquad (1)$$

at which aij (i, j =1,⋯n) are the comparison ratios in the pairwise comparison matrix and n is number of alternatives.

iii. Consistency Verification:

- Check the consistency of pairwise comparisons using the Consistency Ratio (C.R.).
- Calculate the Consistency Index (C.I.) and compare it with the Random Index (R.I.) to ensure the matrix is consistent (C.R. < 0.1).

$$C.R. = \frac{C.I.}{R.I.} \qquad (2)$$

Here, C.I. is the Consistency Index, and C.I. is introduced as

$$C.I. = \frac{\lambda_{max} - n}{n-1} \qquad (3)$$

of which n is the number of criteria and λ max is the biggest eigenvalue, and is calculated as the following

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(B\omega)_i}{n\omega_i} \qquad (4)$$

iv. Weighting Factors Calculation:

- Determine the overall priorities or weighting factors for the impedance factors in emergency routing.
- Calculate overall priorities for each alternative using the formula

$$\omega_i = \sum_{j=1}^{m} a_j b_{ij} \qquad (5)$$

- Validate the overall C.R. to ensure consistency.

$$C.R. = \frac{\sum_{j=1}^{m} a_j C.I._j}{\sum_{j=1}^{m} a_j R.I._j} \qquad (6)$$

v. Integration with Dijkstra:

- Integrate AHP-derived weighting factors with the Dijkstra algorithm for emergency routing.
- Redefine road lengths in the Dijkstra model based on the weighting factors to account for impedance factors.
- This integration aims to optimize the minimal travel time for emergency routing, as illustrated in Fig. 2.

Incorporate AHP Weighting Factors:

- Apply the weights derived from the AHP process to adjust the significance of various impedance factors (e.g., road type, junction delays) in the routing model.
- Modify the traditional Dijkstra algorithm to account for these weighted factors, thereby reflecting real-world conditions more accurately.

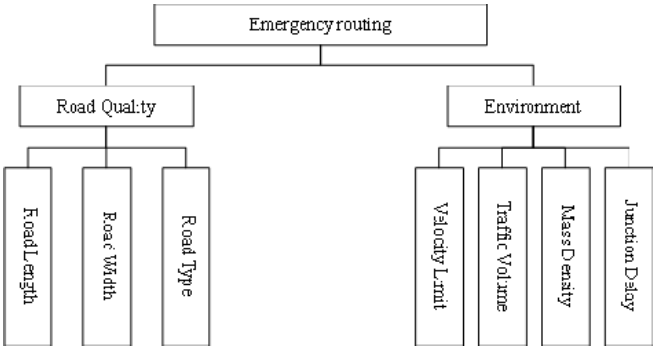


Figure 1. The hierarchy of emergency routing

TABLE I

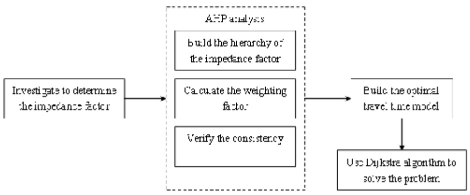
SCALES IN PAIRWISE COMPARISONS

Importance Scale	Definition
1	Equally Importance
3	Moderate Importance
5	Strong Importance
7	Extreme Importance
9	Extremely More Importance
2, 4, 6, 8	Intermediate values between Adjacent Scale Values

TABLEII

THEWEIGHTINGFACTOROFIMPEDANCEFACTORS

Road Length	**Road Width**	**Road Type**	**Traffic Volume**
0.480	0.195	0.075	0.140
Mass Density	**Velocity Limit**	**Junction Delay**	-
0.065	0.030	0.015	-



IV.Integration of AHP with Dijkstra

Combine AHP-derived weights with Dijkstra's algorithm by adjusting the road length in the routing model to reflect impedance factors. This integration creates a minimal travel time model tailored for emergency routing.

The final approach integrates AHP with Dijkstra's algorithm in GIS to enhance emergency response efficiency, providing more practical and effective routing for fire services.

Figure 3. The classical Dijkstra algorithm routing result in GIS

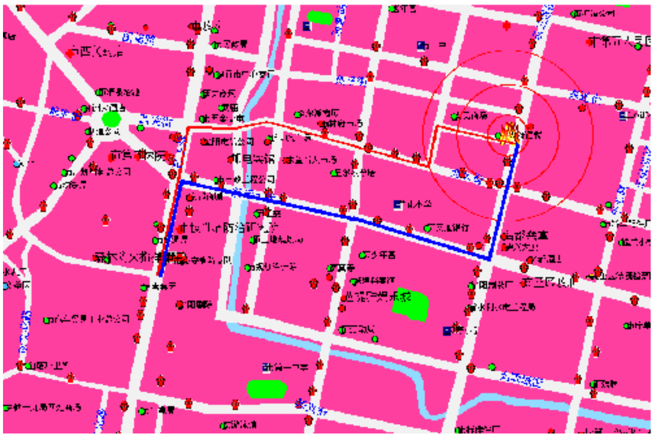


Figure 4. The AHP enhanced Dijkstra algorithm routing result in GIS

Figure 5 The shortest route and the best route results between points 0 and 6 respectively

V. Experiments and Analysis

A.Classical Dijkstra Algorithm in GIS

The classical Dijkstra algorithm was tested in a GIS environment using an assumed fire scene in Liaoyang City, China. This method provided the shortest path from the fire station to the fire scene, as illustrated in Fig. 3. However, this approach did not account for real-world road conditions such as narrow road widths, junction delays, and high-density areas, which could result in delays for the fire services. Consequently, despite its theoretical shortest path, the classical Dijkstra routing scheme may not be practical in emergency situations.

B.Enhanced Dijkstra Algorithm with AHP in GIS

The enhanced Dijkstra algorithm, which incorporates AHP analysis, was tested under the same conditions as the classical method. The enhanced algorithm, as shown in Fig. 4, considers impedance factors like road type, junction delays, and mass density. According to feedback from experienced firemen, the route produced by the enhanced Dijkstra algorithm aligned better with real-world conditions and was preferred for emergency response. This indicates that the AHP-enhanced Dijkstra algorithm offers a more practical and effective routing solution compared to the classical approach.

Results and Discussion

The results indicated that the enhanced routing method effectively improved route selection compared to traditional Dijkstra's algorithm. The incorporation of AHP allowed for better consideration of multiple criteria, leading to more reliable emergency response routes.

Conclusion

The integration of Dijkstra's algorithm with AHP in a GIS-based framework offers significant improvements in emergency routing methodologies. This approach enhances decision-making by incorporating multiple criteria and spatial data, thereby optimizing emergency response planning.

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