Intelligent Emergency Evacuation Model for West Lake Scenic Area Based on Path-Flow Feedback Network and Evacuation Cost

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Abstract. If a senic spot is too crowded, there will be a stampeded accident. The existing emergency evacuation methods can be divided into two categories. The evacuation model without information feedback develops routes according to the flow of people at the beginning of the model, with high computing efficiency, but does not take into account the irregular movement of tourists. The model with information feedback takes into account the dynamics and adjusts the visitors' routes in real time, which can achieve the best evacuation effect. In this paper, an intelligent emergency model with information feedback based on runoff feedback and evacuation cost is studied to give a reasonable evacuation method based on actual visitor density and traffic routes in scenic spots, and help visitors choose the best route to achieve evacuation quickly.

Keywords: component; evacuation optimization; transit network design; information feedback

1 Introduction

West Lake is a renowned natural and cultural scenic spot, it attracts a large number of domestic and international tourists. Each year, it receives around 28 million visitors. When there are many tourists, a stampeded will be occured. Therefore, this article focuses on the research and implementation of intelligent emergency evacuation methods in the West Lake Scenic Area. The objective is to ensure safety while guiding tourists to evacuate quickly and effectively.

Traditional emergency evacuation strategies in scenic areas often rely on planning the shortest evacuation routes without considering the traffic saturation, resulting in longer overall evacuation times. Therefore, this article proposes an emergency evacuation model for the West Lake Scenic Area based on a path flow feedback network.

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Information extracted from the network graph is used as constraint conditions to construct a congestion warning model for attractions. By combining feedback algorithms with traffic conditions, emergency evacuation plans are generated, taking into account the traffic saturation of each evacuation route and the remaining passenger flow evacuation demands. This research focuses on the organization of evacuation and route planning in the event of emergencies in the West Lake Scenic Area.

2 Related work

The safe evacuation of individuals is a crucial consideration for the safety of scenic areas, especially in densely populated tourist spots. Therefore, it is necessary to study the characteristics of evacuation behavior in tourist attractions. When a major emergency occurs, decision-makers need to efficiently transport people and property from dangerous areas to designated shelters within the shortest possible time t. This requires the rational allocation of evacuation routes until the emergency evacuation process is completed.

The network-based emergency evacuation model is constructed by representing relevant entities within the evacuation area as nodes and connecting them with actual pathways as edges to establish the connectivity of the emergency evacuation network graph. Subsequently, the attributes of nodes and edges are determined based on factors such as the capacity of entities, the length of paths, and the speed at which visitors move. Finally, the density of individuals is used as a criterion to assess the emergency evacuation. It checks whether the density of individuals at all nodes is within the safe level. If the density at a particular node exceeds the safety standard, an emergency evacuation plan is formulated. The emergency evacuation process is simulated by considering the positions and states of individuals within the network structure as they change over time[1].

Network node alerting is a fault prediction technique based on the connectivity graph of a network. It analyzes and alerts for data anomalies in network nodes. By identifying the abnormal node as the initial node, finding nodes connected to the abnormal node through directed edges, which are considered as associated nodes. A network anomaly subgraph is then constructed based on the abnormal node and its associated nodes. Within this subgraph, relevant feature indicators are used to calculate the current anomaly scores for each node. Finally, the anomaly scores are combined to provide an alert for network anomalies. Han Yan et al. [2] utilizes the topological structure model of the Space L tourism traffic network. The analysis examines the impact of nodes within the network and the tourists' travel experience. This approach aims to prevent safety incidents and ensure the management of scenic areas and tourism safety systems are well-supported. Cheng Rui et al. [3] devised evacuation plans based on specified warning indicators such as peak saturation, platform passenger density, and temperature.

In general, during the evacuation of a crowd, the principle of the shortest path is commonly adopted. This principle involves planning an evacuation route that is the shortest in distance based on experience, aiming to escape from the dangerous area as quickly as possible. Shen et al. [4] constructed a macroscopic evacuation path model based on network flow algorithms. Li et al. [5] proposed a heuristic fusion algorithm for optimizing network evacuation paths. Yamada [6] utilized the minimum-cost maximum-flow problem from operations research to evacuate traffic in emergency situations, assuming that all individuals take the shortest path to reach a safe area, thus minimizing the total evacuation distance.

3 Evacuation Model Based on Evacuation Cost

3.1 Data Description

This study utilizes data specific to the West Lake scenic area, including information such as the location of each scenic spot, their respective areas, connectivity between the spots, distances between them, and the spatial distribution and quantity of tourists at different times. Additionally, there is information available on transportation routes, facilities, and nearby stops associated with each scenic spot. Each scenic spot is considered as a node in the network graph. Edges represent the paths that individuals can take between two nodes, abstracting the walkable routes. The number of people that need to be evacuated can be estimated based on the area of each scenic spot. According to [7], individuals will be difficult to maintain normal mobility at a population density greater than $1.8/\mathrm{m}^2$. Afterwards, the information in the network connectivity graph is refined and updated, and feedback is utilized to simulate the entire evacuation process.

3.2 Evacuation Costs of Scenic Spots

The evacuation cost of scenic spots describes the cost of the process from the beginning to the end of the evacuation of tourists in scenic spots. It is determined by the time-consuming evacuation of tourists in the scenic spot, the number of tourists, the convenience of transportation and other factors. In actual evacuation, the higher the evacuation cost of scenic spots, the longer the queue time for evacuation and the higher the evacuation cost.

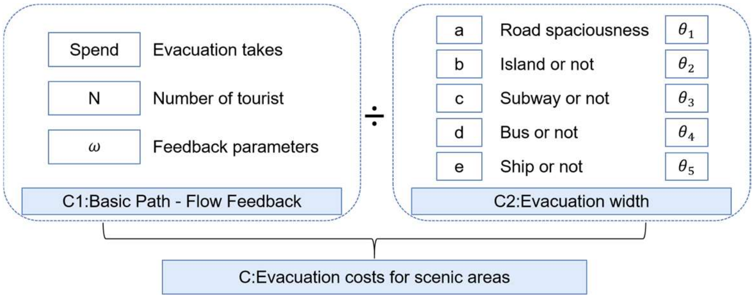


Fig. 1. Determinants of evacuation cost in scenic spots

Before describing the evacuation cost of a scenic area, it is necessary to calculate the time cost of evacuating tourists for each path ($Spend_i$). It represents the time required for all tourists in that scenic spot to evacuate. Due to the urgency and chaos of the evacuation process, the calculation is based on the maximum path within the scenic area and the minimum speed at which tourists can move.

$$Spend_i = \frac{d_{imax}}{v_{imin}} \quad (1)$$

here, d_{imax} is the maximum distance to exit i (distance), and v_{imin} is the minimum speed at which tourists evacuate towards exit i. By accumulating the number of tourists and the corresponding evacuation time for each exit point, the total cost of tourist evacuation C_1 can be obtained.

$$C_1 = \sum_{i=1}^{n} Spend_i N_i^{\omega} \quad (2)$$

here, $Spend_i$ represents the evacuation time cost for the i-th path, N means the number of tourists on the i-th path, ω is the parameter that represents the impact of tourist quantity on the evacuation cost, and a larger ω indicates a greater impact on the evacuation time. In emergency evacuations, the premise is often that the tourist density is too high for warning, so ω is assigned a larger value. A larger value of C_1 indicates a longer evacuation time cost for the corresponding scenic spot [8].

It is worth noting that there is another significant factor to consider in the selection of actual evacuation routes, which is the evacuation capacity of the scenic area's transportation. This coefficient refers to the acceptance capacity of a scenic spot as a destination. It is calculated based on the convenience of transportation routes (such as road width and whether it is an island) and transportation facilities (such as the presence of a subway station within 1 kilometer, the passage of buses, or the need for boat travel). The unique evacuation capacity C_2 of each scenic spot is obtained through comprehensive calculations. This coefficient has great practical significance for various scenic areas in West Lake. For example, if Three Pools Mirroring the Moon becomes crowded during an evacuation, a large number of people will be directed to the nearby Mid-lake Pavilion for evacuation. However, we notice that Mid-lake Pavilion is located in the middle of the lake and can only be accessed by boat. The speed of transportation is slow and the evacuation capacity is small. Evacuating people to this location would not only result in extremely low evacuation efficiency but also pose a risk of overcrowding with insufficient time to evacuate, leading to a higher risk of congestion. On the other hand, If the evacuation is directed towards scenic areas with subway stations, it will facilitate the evacuation of a large number of tourists and greatly ensure their safety. Based on this background, we calculate the evacuation width of scenic spots as following:

$$C_2 = \sum_{i=1}^{n} \theta_1 a_i + \theta_2 b_i + \theta_3 c_i + \theta_4 d_i + \theta_5 e_i \quad (3)$$

In the above equation, i represents the different exits of the scenic spot, n represents the total number of exits, and θ represents the weight of each factor in the calculation of the overall evacuation width. In the application process in West Lake Scenic Area, we identified the following five factors that have the greatest impact on the surrounding area: a) Road width, b) Island status, c) Subway station within a kilometer, d) Presence of bus routes, e) Need for boat transportation. Based on actual data reports, it is evident that the subway availability has the highest proportion, while the presence of islands and the requirement for boat transportation impose the greatest limitations on evacuation width. Therefore, in practical applications, the values of θ_{1-5} are typically set as 0.15, 0.15, 0.3, 0.2, and 0.2, respectively. A higher value of C_2 indicates a larger evacuation width in the area, indicating a stronger. 0 shows all of the determinants.

In summary, based on the above discussion, the evacuation cost of the scenic area C_{All} can be obtained:

$$C_{all} = C_1/C_2 = \frac{\sum_{i=1}^{n} Spend_i N_i^{\omega}}{\sum_{i=1}^{n} \theta_1 a_i + \theta_2 b_i + \theta_3 c_i + \theta_4 d_i} \quad (4)$$

In the above equation, when C_{all} is 0-0.516(smaller), the evacuation cost of the evacuation scenic spot is less and can be allocated to a relatively large number of evacuees. When C_{all} is 0.516-0.741(medium), the evacuation cost of the evacuation scenic spot is moderate, and the evacuees should be appropriately allocated. When $C_{all}$is 0.741-1(larger), the evacuation cost of the evacuation scenic spot is larger, and the corresponding evacuees are less [2].

3.3 Tourists' Path Selection Model

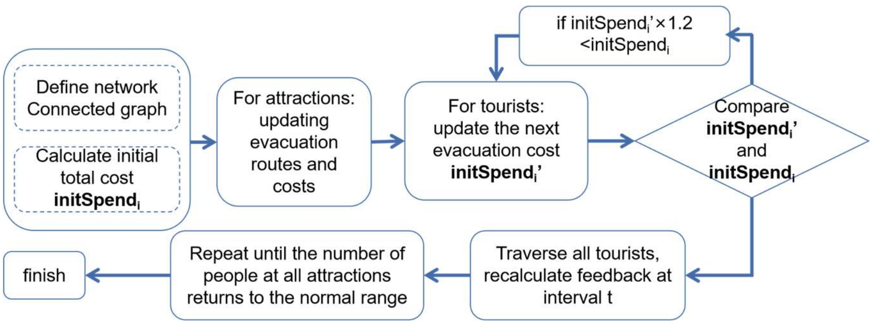


Fig. 2. Emergency evacuation flow chart

For tourists, the choice of their path is often based on the current node's crowd density, the distance to exits, and the evacuation coefficient of the destination attraction. (0)

Step1: Define the initial network connectivity graph model according to the known distribution data of attractions in West Lake. Generate a large number of tourists using random values and assign initial values to the nodes. Then, iterate through each attraction and calculate the shortest evacuation path from the current node for the tourists in each attraction, which serves as the initial target path. Calculate the total cost of the current path as the initial total cost $initSpend_i$ required for evacuating all the tourists from the current node.

Step2: Confirm the evacuation cost of an individual attraction to implement feedback. Based on section 2.2, the basic path-flow cost of a node is given $C_1 = \sum_{i=1}^{n} \mathrm{Spend}_i N_i^{\omega}$. Assuming the travel route is from attraction i to a nearby attraction j, the evacuation cost Spend'(i,j) incurred is given by: Spend'(i,j)= $\mathrm{Spend}_i N_{(i,j)}^{\omega}$, Where $N_{(i,j)}$ represents the number of tourists from attraction i choosing attraction j as the next destination. Using this information, the shortest evacuation path cost Spend'_{all} can be updated.

Step3: To achieve information feedback, update the evacuation cost for each tourist's next step. Based on section B, the updated evacuation cost $\mathrm{initSpend}'_{(i,j)}$ from attraction i to j for all exits (excluding the initial choice) is calculated as: $\mathrm{initSpend}_{(i,j)}' = C_{1(i,j)} C_{2j} + \mathrm{Spend}'_{all(j,k)}$, where $C_{1(i,j)}$ is the traveler evacuation costs, C_{2j} is the evacuation coefficient of attraction j, $\mathrm{Spend}'_{all(j,k)}$ is the shortest evacuation route for attraction j to exit k. Iterate through all remaining exits and select the minimum $\mathrm{initSpend}_{(i,j)}'$ as the current minimum evacuation cost $\mathrm{initSpend}_{(i,j)}'$for tourist i.

Step4: Compare the initial cost $\mathrm{initSpend}_{(i,j)}$ with the current minimum evacuation cost $\mathrm{initSpend}_{(i,j)}'$. If 1.2 times of $\mathrm{initSpend}_{(i,j)}'$ is less than $\mathrm{initSpend}_{(i,j)}$, choose $\mathrm{initSpend}_{(i,j)}'$ as the initial path cost for the next feedback iteration, and update the tourist's path accordingly.

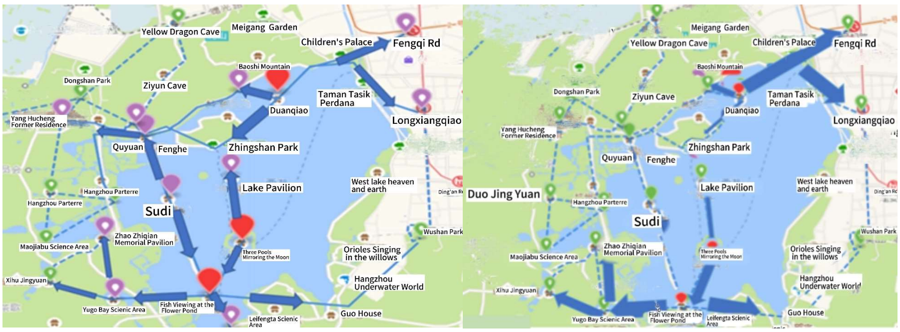
Step5: Iterate through all the tourists in the model and select a path for each tourist. Recalculate the paths for all tourists at regular intervals of time (step 2-4). Allow the model to perform data feedback every t units of time, displaying the changes in tourists' speed and position information.

Step6: Repeat the above steps until the number of people in all attractions returns to the normal range, the evacuation is completed.

4 Evaluation comparison

The network evacuation model is a model applied to crowd evacuation scenarios, aiming to simulate human behavior and predict and optimize the evacuation process. It is divided into non-feedback and feedback evacuation models. The non-feedback network evacuation model is a static network model where, at the beginning of the model computation, the starting point, destination, and evacuation route for each individual need to be determined. This kind model is simplicity and ease of implementation, allowing for quick simulation of large-scale crowd evacuation processes. However, the calculation results are largely influenced by the predefined evacuation strategy. If the predefined evacuation strategy is effective, the simulated evacuation time will be shorter. Conversely, if the predefined evacuation strategy is not well-designed, the simulated evacuation time may be longer. Compared to the non-feedback network evacuation model, the feedback network evacuation model is a dynamic model. This allows tourists to recalculate the optimal evacuation strategy by considering factors such as the feedback strategy of information in the path, the distances between nodes, the evacuation flow velocity, and the transportation convenience of each node. (0)

The design of emergency evacuation models is of utmost importance in ensuring the safety of tourists in the West Lake scenic area. By simulating both the non-feedback emergency evacuation model and the feedback network-based emergency evacuation model, a better understanding of crowd behavior and path selection in evacuation scenarios can be achieved. In particular, the results of the non-feedback emergency evacuation model, as shown in 0(a), are not ideal. Evacuating the crowd from the warning nodes along the shortest path and having each individual choose the shortest route will result in the underutilization of other paths, thereby limiting the overall evacuation capacity of the entire scene. In addition, this model does not analyze the evacuability of idle attractions, which may result in the emergence of new warning nodes, leading to increased crowding and casualties. In the evacuation results diagram of the emergency evacuation model without information feedback, the Three Pools Mirroring the Moon scenic spot triggers a warning. There is an evacuation route towards the Mid-lake Pavilion, which is only connected to other attractions via boats. The evacuation efficiency along this route cannot match the expected results. If there is a sudden increase in the number of people at the Mid-lake Pavilion, it would pose greater challenges for evacuation.



(a)without using information feedback (b)using information feedback

Fig. 3. Comparison of the results of the emergency evacuation model with and without information feedback

Table 1. evacuation COST Contrast

Evacuation mode's evacuation cost	**Evacuation directions**				
	Fengqi Road	***Zhongshan Park***	***Mid-lake Pavilion***	***Guutan scenic spot***	***Su Causeway spring dawn***
Traditional method	medium	medium	medium	medium	medium
Our method	smaller	larger	larger	smaller	medium

In comparison, the emergency evacuation model based on path-flow feedback network incorporates modeling of flow feedback, allowing for more accurate prediction of crowd behavior and providing more reasonable path selection solutions. The evacuability of attractions is taken into account in this model, which enable better allocate the crowd flow and thereby enhancing evacuation efficiency and the distribution of evacuees in terms of connectivity between attractions.

The thickness of the evacuation routes from the warning nodes to other nodes, as shown in 0(b), represents the allocated evacuation flow based on the connectivity of safe nodes and the path flow coefficient feedback. For example, if the Broken Bridge attraction triggers a warning, due to the high flow capacity of the Fengqi Road subway station and its short distance from the warning node, a relatively large evacuation flow is allocated to it. On the other hand, Zhongshan Park, which is adjacent to Fengqi Road, has only two pathways, so a relatively smaller flow is allocated to it. This model, whether in terms of evacuation time or the distribution of individuals based on attraction connectivity, closely resembles the actual scenario. Therefore, it demonstrates high feasibility and practicality in real-world applications.

5 Conclusion

An emergency evacuation model by utilizing dynamic network graph data and visitor characteristics is established in this paper. Through measures such as visitor density regulation, route planning, and real-time adjustments, it aims to assist West Lake managers in effectively monitorinsg and managing visitor flows, balancing the load on attractions, and resolving congestion crises. This article focuses on the following aspects of research: 1) Constructing a network connectivity graph of the West Lake scenic area based on simulated data of attractions and visitors. 2)Calculate the evacuation time based on the tourist data during the evacuation period and the density of tourist attractions. 3) Establishing an emergency evacuation model to demonstrate the entire process of emergency evacuation, including warning, evacuation, and data updating. 4)Comparing with other algorithms to showcase the improvement in evacuation efficiency achieved by this project.

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