Dynamic evacuation path planning in complex subway station hubs: a model calibrated by field and VR empirical data

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Abstract A complex deep transfer subway station hub may need to consider elevators as an auxiliary evacuation method. Under the conditions of new elevators and evacuation modes, a dynamic path planning model was proposed. The subway station space is abstracted into a three-dimensional evacuation network, and the values of the edges are determined by the building foundation properties, real-time density, and predicted smoke diffusion values. Furthermore, the response of pedestrians to dynamic path changes was measured through virtual reality experiments, and evacuation dynamics data at elevators and fire doors were obtained through on-site experiments. The research results have demonstrated the feasibility and effectiveness of the model.

Keywords subway station hub, elevator, evacuation, path planning, VR experiments

Introduction

Multi-line deep transfer subway station hubs are characterized by enclosed underground spaces, complex spatial layouts, intertwined passages, and diversified evacuation routes, which make it difficult for pedestrians to identify appropriate evacuation paths during emergencies. Specifically, in deep subway stations, elevator-assisted evacuation may be necessary. Moreover, hazards such as smoke diffusion or power failures may disrupt originally designed evacuation paths and guidance systems, further increasing evacuation uncertainty. Therefore, it is urgent to develop a dynamic evacuation route planning method that can coordinate building spatial characteristics and adapt to evolving disaster conditions.

However, existing studies and applications mainly focus on dynamic path optimization under changing environmental conditions, while insufficient attention has been paid to pedestrians' behavioral responses to dynamically changing evacuation routes. In practice, evacuees may hesitate or fail to follow updated guidance when evacuation paths are adjusted, which can significantly influence evacuation efficiency. Therefore, it is necessary to consider pedestrian responses to dynamic path changes when developing evacuation path planning models for complex subway station hubs.

Method

Based on the complex transfer subway station hub considered in this study, the key spatial locations along evacuation routes are abstracted as network nodes, while weighted directed edges are used to represent the evacuation paths connecting these nodes. In this manner, a three-dimensional evacuation network is constructed, as illustrated in Figure 1.

Considering the practical evacuation processes, the edge cost should comprehensively reflect the geometric characteristics of evacuation paths, differences in evacuation ability of facilities, the global distribution of evacuees (pedestrians' density), and the influence of hazards on evacuation path planning within the subway station. Therefore, the value of an edge is defined as the product of the equivalent path length and a risk coefficient, which incorporates both crowd density risk and fire hazard risk. By integrating the effective path length with dynamic risk factors, the equivalent evacuation cost of edge ij is defined as in equation (1).

$$C_{ij} = L_{ij}^{\text{eff}} \cdot f(\rho_{ij}) \cdot g(h_{ij}), \tag{1}$$

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where C_{ij} denotes the equivalent evacuation cost (or cost value) of edge ij, L_{ij}^{eff} represents the equivalent length of edge ij, and $f(\rho_{ij})$ and $g(h_{ij})$ denote the density risk coefficient and fire risk coefficient associated with edge ij, respectively.

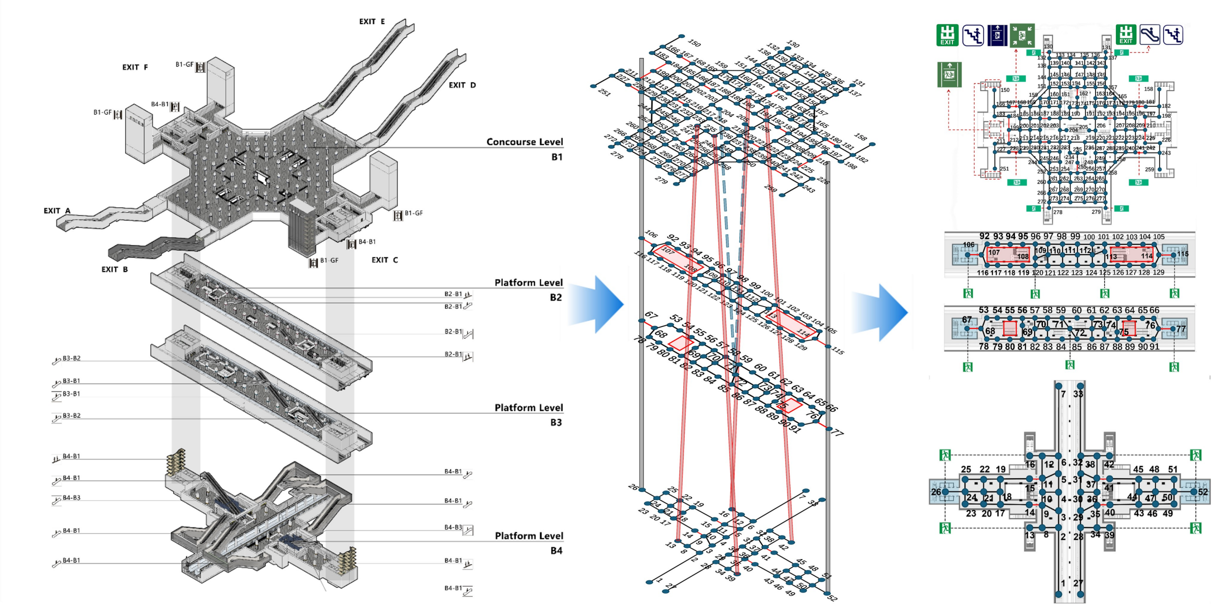

Figure 1: Abstract process of evacuation network from a real subway station hub.

Furthermore, the parameters will be calibrated by our previous field evacuation experiments and future virtual reality (VR) experiments, which can be seen from Figure 2.

Figure 2: Field experiments and VR experiments.

Result

The simulation results of a demo show that the proposed dynamic path planning model can effectively couple the evacuation capacity of buildings (facilities), smoke diffusion, and crowd movement (density changes), and re-plan safer evacuation paths in real time (Figure 3), providing technical support for dynamic evacuation path planning and guidance of complex subway station hubs in fire situations.

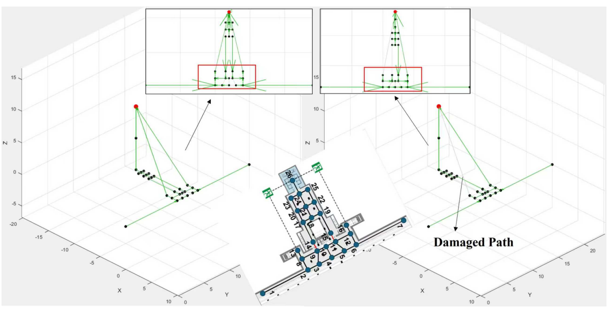

Figure 3: Application example of demo simulation results.