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August 10th ~ 12th, 2026

National University of Mongolia, Ulaanbaatar, Mongolia



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KOREAN INSTITUTE OF SMART MEDIA

NATIONAL UNIVERSITY OF MONGOLIA

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Oral Session 2

Time	August 11 Tuesday (09:30 ~ 11:00)
Room	E-Library of NUM Room 204
Session Chair	Oyundolgor Khorloo,National University of Mongolia

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Optimized Evacuation Route Guidance Mechanism based on Refined Floyd-Warshall Dynamic Programming Approach*

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ABSTRACT

In modern large-scale shopping malls, logistics warehouses, and other complex building structures, large-scale disasters such as fires and explosions can cause severe casualties. In particular, securing effective evacuation route guidance during the initial stage of a disaster is challenging because smoke, heat, toxic gas, blocked corridors, and crowd congestion dynamically change the safety of adjacent spaces. Conventional shortest-path algorithms primarily focus on physical distance and do not sufficiently account for real-time fire environments. To address these limitations, this paper proposes an optimized evacuation route guidance mechanism based on a refined dynamic programming approach to the Floyd-Warshall algorithm. The proposed method models an indoor facility as a weighted graph and incorporates real-time risk levels into edge weights. By precomputing all-pairs evacuation route tables and refining them according to detected hazards, the system can immediately retrieve safe candidate routes from any occupant location to multiple exits. The proposed mechanism is expected to reduce route decision latency and improve survival probability in complex disaster situations.

KEYWORDS : Evacuation Rute Guidance; Floyd-Warshall Algorithm; Dynamic Programming; Fire Disaster; Risk-aware Path Planning; Indoor Navigation; Disaster Response Robot

1 INTRODUCTION

Large-scale indoor facilities have become increasingly complex because of multi-floor structures, underground spaces, logistics zones, and mixed-use commercial areas. In such environments, evacuation during a fire or explosion is difficult because occupants may not be familiar with the building layout, and ordinary exit signs may guide people toward corridors that have already become dangerous. Recent studies on fire evacuation emphasize that static evacuation routes cannot adequately account for changing smoke spread, reduced visibility, and route blockages [1], [2].

Conventional path-planning algorithms such as A* and Dijkstra are widely used in indoor navigation. However, they generally compute routes based on geometric distance or static cost values. In a real fire environment, the shortest physical route may not be the safest route. A corridor near a fire source, a smoke-filled stairway, or a congested passage can be shorter but more dangerous than an alternative path. Moreover, when multiple evacuees must be guided to multiple exits simultaneously, repeated single-source route computations can increase response latency.

To overcome these limitations, this paper proposes a refined Floyd-Warshall dynamic programming approach for optimized evacuation route guidance. Floyd-Warshall is suitable for computing all-pairs shortest paths in a graph [9], [10]. In the proposed mechanism, this property is extended to disaster evacuation by precomputing route tables among all major indoor nodes and dynamically refining edge weights according to real-time hazard information. Thus, once a disaster occurs, the system can immediately retrieve route candidates from any starting node to any exit without repeatedly executing single-source pathfinding.

2 RELATED WORK

2.1 Real-Time Fire Evacuation Route Planning

Real-time fire evacuation planning has recently attracted attention because pre-established evacuation routes cannot always reflect rapidly changing fire conditions. Huang et al. proposed an automatic model for selecting emergency evacuation routes based on pedestrians' decision-making processes [1]. Bai et al. proposed an indoor route-determination method based on dynamic fire-risk assessment and an enhanced A* algorithm [2]. Zuo et al. considered smoke, visibility, temperature, and evacuation speed in a dynamic avoid-smoke A* method for metro station fire scenarios [3]. These studies show that evacuation routing must account for changing environmental hazards rather than relying solely on physical distance.

Although these approaches improve the safety of route selection, many still perform route planning from a particular source to a particular destination or require repeated computation whenever the source, exit, or fire state changes. In large buildings where many occupants must be guided simultaneously, repeated computation can become inefficient. Therefore, an all-pairs route precomputation strategy is useful for enabling immediate route retrieval during the initial stage of disaster response.

2.2 Indoor Navigation, Digital Twin, and Robot-Guided Evacuation

Emergency evacuation systems increasingly use GIS, three-dimensional building models, IoT sensors, and digital twins to improve situational awareness. Tyagi et al. proposed a 3D model-based framework for real-time emergency evacuation using GIS and IoT devices [4]. Ding et al. developed an intelligent emergency digital twin system for monitoring building fire evacuation using computer vision and deep learning [5]. These studies indicate that emergency route planning can be strengthened by integrating building models and sensor data.

Robot-guided evacuation has also emerged as an important research direction. Sriniketh et al. proposed robot-aided evacuation path planning for fire drills in buildings [6].

Nayyar and Wagner analyzed evacuee behavior during robot-guided evacuations and highlighted the importance of modeling human response to robot guidance [7]. These studies support the need for a route-guidance mechanism that can provide fast and reliable instructions via robots, dynamic signage, or mobile interfaces.

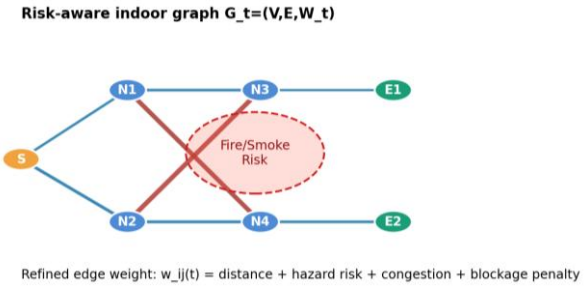


Figure 1: Risk-aware indoor graph model for evacuation route planning.

3 PROPOSED METHOD

3.1 Indoor Disaster Graph Model

The proposed system represents an indoor facility as a time-dependent weighted graph G_t = (V, E, W_t), where V is the set of indoor nodes, E is the set of accessible edges, and W_t is the time-dependent edge-weight matrix. Nodes include exits, corridor intersections, stair entrances, rooms, emergency equipment points, and robot guidance positions. Edges represent corridors, doorways, ramps, and stair passages.

In a conventional shortest-path model, the edge weight is usually determined by physical distance. In a disaster environment, however, route safety depends on distance, hazard exposure, congestion, and blockage. Therefore, the proposed model defines the refined edge weight as w_ij(t)=alpha*d_ij + beta*R_ij(t) + gamma*C_ij(t) + delta*B_ij(t). Here, d_ij is the physical distance, R_ij(t) is the real-time disaster risk score, C_ij(t) is the congestion score, and B_ij(t) is the blockage penalty. If an edge becomes physically blocked or exceeds a safety threshold, the system assigns a very large penalty value to prevent that edge from being selected.

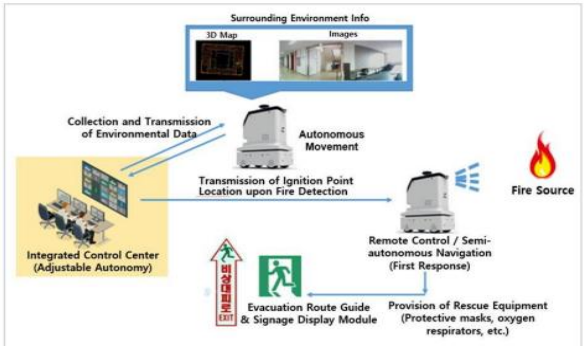


Figure 2. First-Response Fire and Disaster Response Robot

3.2 Refined Floyd-Warshall Process

The conventional Floyd-Warshall algorithm updates the shortest distance between nodes i and j by checking whether an intermediate node k provides a lower cost: dist[i][j] = min(dist[i][j], dist[i][k] + dist[k][j]). The proposed mechanism refines the evacuation process by using risk-aware weights rather than distance-only weights. The system maintains two matrices: Dist[V][V], which stores the minimum risk-aware cost between all node pairs, and Next[V][V], which stores the next node required for path reconstruction.

The algorithm consists of two stages. First, before a disaster occurs, the building layout is converted into a graph, and a baseline all-pairs route table is computed. Second, when information about fire, smoke, congestion, or blockage is detected, the relevant edge weights are updated, and the route table is refreshed or partially repaired. The selected exit e* is determined by e* = arg min Dist[s][e], where s is the occupant or robot location, and e is a candidate exit.

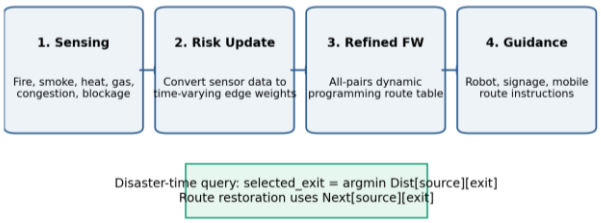


Figure 3: Proposed evacuation route guidance mechanism based on refined Floyd-Warshall dynamic programming.

3.3 Evacuation Guidance Output

After route selection, the proposed system provides evacuation guidance through one or more output channels. In robot-assisted scenarios, mobile or stationary robots can be deployed at major decision nodes such as corridor intersections and stair entrances. These robots can provide voice guidance, LED arrows, screen-based instructions, or gesture-based direction signals. In smart-building scenarios, the same route information can be transmitted to dynamic signage, mobile applications, or public announcement systems.

The proposed mechanism is especially suitable for multiple evacuees because the precomputed route table supports immediate lookup for many source nodes. Instead of repeatedly executing A* or Dijkstra for each evacuee, the system queries the precomputed matrix and selects the safest available route to a suitable exit.

4 EVALUATION DESIGN

4.1 Complexity Comparison

The proposed mechanism is compared with A* and Dijkstra from the perspective of emergency evacuation. A* is efficient when the start and goal are fixed, but it must be executed repeatedly when there are many evacuees and exits. Dijkstra can compute paths from a single source to all exits, but it still requires repeated execution for many starting points [8]. In contrast, Floyd-Warshall computes all-pairs routes in advance. Therefore, the proposed method is advantageous when the building graph is known, and many evacuees require simultaneous route guidance.

From an algorithmic viewpoint, A* provides efficient target-oriented search, but it should be executed repeatedly when exits or occupant locations change. Dijkstra provides stable single-source route computation, but each evacuee source still requires a separate run in a multi-source scenario. The refined Floyd-Warshall mechanism incurs a higher precomputation cost. Still, it enables disaster-time route retrieval via a table lookup, making it suitable for simultaneous multi-source and multi-exit guidance.

4.2 Scenario and Metrics

The proposed method can be evaluated using a simulated large-scale indoor facility such as a shopping mall or logistics warehouse. The indoor environment is converted into a graph with corridors, exits, intersections, and restricted zones. Fire scenarios are generated by varying the ignition location, the direction of smoke spread, the presence of blocked edges, and the crowd density.

The evaluation compares four methods: static exit signage, A*, Dijkstra, and the proposed refined Floyd-Warshall mechanism. The main metrics are route decision time, average evacuation cost, hazard exposure, exit distribution balance, route failure rate, and re-routing responsiveness. The expected result is that the proposed method reduces disaster-time route decision latency because route retrieval is based on precomputed all-pairs tables. In addition, by incorporating real-time risk values into edge weights, the system can avoid hazardous areas even when those areas are physically short.

5 DISCUSSION AND DEPLOYMENT CONSIDERATIONS

5.1 Deployment in Smart Buildings

The proposed mechanism assumes that the building topology can be represented as a graph and that hazard values can be obtained from sensors, simulation modules, or control-center inputs. In practical deployment, the graph can be generated from architectural drawings, BIM data, or manually defined evacuation maps. The graph should be updated when a corridor is renovated, a temporary wall is installed, or an exit is restricted. This management process is important because the quality of route guidance depends on the correctness of the indoor graph.

During normal operation, the baseline route table can be stored in the building control server or in an edge computing device. When a disaster is detected, local sensing devices can update only the weights of the affected corridors. For example, if smoke density increases near a stairway, the risk penalty for adjacent edges increases. If a passage is physically blocked, a very large penalty is assigned. This allows the system to avoid dangerous areas while maintaining rapid route retrieval for multiple occupants.

5.2 Limitations and Human Factors

The proposed method focuses on route computation and guidance, but the actual evacuation outcome also depends on human behavior. Occupants may ignore guidance, follow crowds, return to retrieve belongings, or hesitate when instructions conflict with familiar routes. Therefore, route guidance should be delivered through redundant channels such as LED signs, voice messages, mobile notifications, and robot-based direction cues. Repeated and consistent messages can reduce confusion at decision points.

Another limitation is that dynamic edge weights require reliable sensing and communication. If sensor data are delayed or noisy, route selection may be affected. To reduce this risk, the system should combine multiple sources of information and define conservative safety thresholds. Future implementation should also consider fail-safe behavior, such as reverting to verified safe exits when real-time data are unavailable.

6 CONCLUSIONS

This paper proposed an optimized evacuation route guidance mechanism based on a refined dynamic programming approach to Floyd-Warshall. The proposed method models large-scale indoor facilities as weighted graphs and integrates real-time disaster risk into edge weights. Unlike conventional shortest-path algorithms that primarily focus on physical distance or require repeated computation, the proposed mechanism precomputes all-pairs routing information. It supports immediate route retrieval for multiple evacuees and exits.

The proposed mechanism can be integrated with disaster-response robots, dynamic signage, and mobile evacuation applications. By combining risk-aware graph modeling with all-pairs route computation, this approach is expected to reduce route decision latency and improve evacuation safety in complex fire environments. Future work will validate the mechanism in high-fidelity fire simulations and physical mock-up spaces. It will incorporate human factors such as panic behavior, group movement, and trust in robot guidance.

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