Comparative Analysis of Evacuation Strategies: Awareness and Pathfinding *

Álvaro Serrano[1], Giuseppe Vizzari[2], and Marin Lujak[†1]

[1]CETINIA, University Rey Juan Carlos, Madrid, Spain
[2]Department of Informatics, Systems, Communication, University of Milano-Bicocca

Keywords Pedestrian evacuation, Pathfinding, Agent-Based Simulation, Dynamic Routing

Extended Abstract

Efficient evacuation planning is crucial during emergencies. Agent-based simulations offer a controlled environment to evaluate how different routing strategies and levels of situational awareness affect evacuation efficiency [1, 4, 5]. In our study, we model evacuees as agents grouped by their starting locations within a building layout, represented as a graph. The agents move toward exits using one of the following two strategies: the *Efficient Paths* approach, which allows agents to dynamically re-compute their routes on the fly in response to changing conditions, and the *Agile Evacuation Routes (AER)* approach. This method dynamically identifies Agile Evacuation Routes by assessing the number, safety, and evacuation time of the paths originating from their intermediate nodes. It evaluates each node's evacuation centrality, ensuring evacuation that is resilient to the fluctuating safety conditions posed by unpredictable hazard dynamics [2]. Additionally, agents are modeled with either *High Awareness* (i.e. they receive continuous updates on the presence of risks in the environment) or *Low Awareness* (gaining information by local perception as they progress in space) [3]. The high awareness approach is only possible in environments able to locate the pedestrians (e.g. smart buildings with indoor localization facilities) and when evacuees can actually receive awareness information about the best route to be followed (e.g. through smart wearable or portable devices, or variable message panels positioned in the environment). The low awareness approach has lower technology requirements and, essentially, a static evacuation plan positioned in strategic locations in the building. The high-awareness scenario is applicable to emergency response systems in environments with controlled access, including hospitals and airports. Here, dynamic routing or static signage is tailored to the available technological infrastructure. Our analysis offers valuable insights into how adaptive routing and the availability of information affect evacuation performance.

Methodology – The simulation employs a building layout (Fig. 1) featuring multiple exits, key waypoints, and designated starting positions. For pedestrian simulation, we employ JuPedSim with the Collision Free Speed Model[1], focusing on pedestrian routing choices. Each evacuee, initially randomly located in the building, selects between two strategies: *Efficient Routes*, which are dynamically computed shortest paths that adapt as hazards evolve, and *Agile Evacuation Routes*. Evacuees with high awareness receive continuous updates that allow them to re-plan their routes as conditions change [4], whereas Low Awareness evacuees rely on information gathered as they progress [3]. Figure 2 illustrates the trajectories of evacuees under different scenarios. In the Low Awareness Agile Evacuation Routes case, evacuees traverse the central corridor until they reach an intersection and initially head toward exit EA; however, upon reaching node 3G, they observe that node 3H is hazardous and thus reverse course to proceed toward exit EB. Conversely, in the High Awareness Agile Evacuation Routes scenario, evacuees use the same corridor but, being pre-informed of the hazard on the path to EA, they directly choose exit EB. Regarding the Efficient Paths strategy, in the Low Awareness scenario, evacuees from the red group follow the shortest route to exit EB without encountering hazards, while those in the blue group attempt to use the shortest path toward the nearest exit (EA); upon arriving at node N, they detect that node O is hazardous and consequently re-route to exit AB via the shortest path. In the High Awareness Efficient Paths scenario, both groups proceed directly to exit AB along the shortest route.

*This work was partially supported by the grant COSASS: PID2021-123673OB-C32 funded by MCIN/ AEI/ 10.13039/501100011033 and by "ERDF A way of making Europe."

†Email of the corresponding author: `marin.lujak@urjc.es`

[1]`https://www.jupedsim.org/stable/pedestrian_models/index.html`

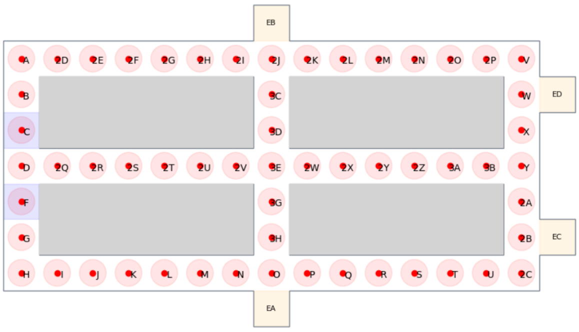

Figure 1: Layout of the simulation environment: zones C and F are starting positions; red markers are potential waypoints/hazards; EA, EB, ED, and EC are exits.

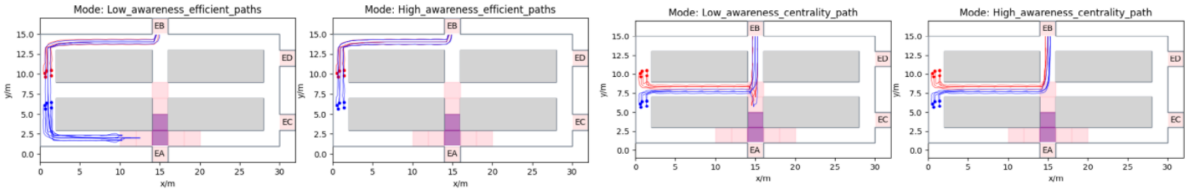

Figure 2: Colored dots are evacuees' initial positions, with colors associated to the two groups considered; lines show their trajectories. Purple areas are hazard zones, while pink areas may become risky over time.

Awareness Level	Pathfinding Algorithm	Time (s)
Low Awareness	Efficient Paths	66.52
High Awareness	Efficient Paths	30.56
Low Awareness	Agile Evacuation Routes	37.40
High Awareness	Agile Evacuation Routes	34.92

Table: Evacuation Times for Different Scenarios

Results – The evacuation times for each scenario are summarized in Table 2. Notably, the *High Awareness + Efficient Paths* combination yielded the fastest evacuation, while the *Low Awareness + Efficient Paths* scenario was the slowest. These findings confirm that dynamic route adjustment plays a critical role in reducing evacuation time [1]. High Awareness significantly reduced evacuation times, particularly when paired with the Efficient Paths algorithm [4]. Although the Agile Evacuation Routes method proved robust under limited information [2], the dynamic re-routing of Efficient Paths only showed its full potential in this simple environment when agents were well-informed [3].

Conclusion – Our simulation environment demonstrates that situational awareness is essential for rapid evacuations. Dynamic shortest-path algorithms provide the best performance when agents receive continuous, real-time information in this context [4], while Agile Evacuation Routes remain a reliable alternative when information is limited [2]. The layout of our simulation environment was relatively simple. In future work, we will perform experiments in more complex layouts with multiple egress possibilities and security conditions that change rapidly in time and space. We also intend to investigate more complex behavioral models and multi-level environments to further refine evacuation strategies.

Bibliography

[1] D. Helbing, I. Farkas, and T. Vicsek, "Simulating dynamical features of escape panic," *Nature*, vol. 407, no. 6803, pp. 487–490, 2000.

[2] M. Lujak and S. Giordani, "Centrality measures for evacuation: Finding agile evacuation routes," *Future Generation Computer Systems*, vol. 83, pp. 401–412, 2018.

[3] S. Ossowski and M. Lujak, "Evacuation Route Optimization Architecture Considering Human Factor," *AI Communications*, vol. 45, pp. 78–89, 2017.

[4] G. Vizzari, L. Crociani, and S. Bandini, "An Agent-Based Model for Plausible Wayfinding in Pedestrian Simulation", *Engineering Applications of AI*, vol. 87, 2020.

[5] K.A.U. Wagoum, A. Seyfried and S. Holl, "Modeling the dynamic route choice of pedestrians to assess the criticality of building evacuation", Advances in Complex Systems, 15(07), p.1250029, 2012.