Review on Evacuation Systems for Indoor Fire Situation

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Abstract. Casualties and huge losses could result from fire disasters in buildings. On the event of fires, evacuation from an isolated place of course becomes difficult and complicated due to factors such as fire spread, panic in evacuee movement and consequent congestion, failure in communication due to errors and delays, etc. This paper aims to compare competitive algorithms used for the calculation of shortest paths or the safest paths to mitigate the problem of evacuation. It also reviews corresponding evacuation models implemented in the past. By comparison with all existing methods, challenging issues are discussed, which should be met to enable basic requirements of an evacuation routing system. We conclude by underlining future directions towards enhancing the abilities for fire evacuation.

Keywords: Evacuation · Emergency · Routing algorithms · Safest path · Congestion

1 Introduction

Fires cause destruction and devastation, costing the lives and livelihoods of people. With increased housing density, it has never been more important to protect against fires and to detect fire risks [1]. Building structures are progressively becoming complex. Innumerable individuals travel through them constantly. Fitting to this intricacy is fundamental to secure lives and comply to safety standards. In the event of fire emergency, individuals' lives are put at risk, and this causes a quick movement of individuals needing to escape from the hazardous area. This brings in the need of emergency navigation systems, as a way of managing safety exit of evacuees when indoor fires occur. It is a corporate practice to make individuals go through pre-planned evacuation drills to make sure that they know how to escape through the infrastructure they are into. Work site readiness is essential, not only to reduce emergency mortality rates, related to emergency events, but also for creating a culture and climate of emergency preparedness. These is also a growing body of evidence that this type of culture can support worker resiliency and help reduce long-term mental health consequences of disaster survivor-ship. Furthermore, a culture and climate of preparedness may empower personal responsibility for employees actions. By understanding their role in supporting the safety of the entire population of occupants, employees may be more likely to ensure that they are personally as well prepared as feasibly possible [2].

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However, this does not realistically picturize the real emergency and dynamics of the fire situation.

Guaranteeing that alarm and evacuation systems frameworks are reliable and productive is the need of the hour. Major trends in the market of fire alarm systems focus on detection systems, put in place for protection of the building population in case of fire and gas leakage. These systems monitor building areas for harmful gases and fire, and provide warning in advance so that appropriate mitigation actions can be taken in a reasonable time. According to Inderpreet Shoker, in the survey report of Fire Alarm Systems Global Market Research for the span 2017–2022 report, growing consciousness about fire protection systems and the perceived benefits of advanced technology for fire prevention are accelerating growth in the fire alarm market. Moreover, investments tend to be associated with retrofits or replacement projects or modernization in developed nations, while developing countries like China, India, etc. are undergoing massive growth propelling investment in grassroots projects. The market of Intelligent Evacuation Systems mainly focuses on software and hardware solution integration developed to promote the individual safety measures in emergencies [3]. Such systems provide a format of alert and notification supporting smooth and trouble - free evacuation during fire situation. Trends are mainly into visual and acoustic alarming for people with impaired hearing, multilingual voice alarming. The market for smart evacuation systems is impacted by increased demand for technologically sophisticated products, increased need for rapid response management for emergency, and supportive regulatory structure.

Egress models, are computer simulation models for fire evacuation which anticipate the time for inhabitants of a building structure to evacuate. Many egress models are like zone models, which determine the time to the beginning of illogical conditions in a building. Egress models are frequently utilized in performance-based design analyses for code compliance of alternative design and for figuring out during egress, where the blockage zones would probably develop. EESCAPE, Simulex, building EXODUS, EGRESS, ELVAC, EVACNET4, EVACS, EXIT89, EXITT, PATHFINDER, are some of the egress models developed for fire evacuation in the past. The next section discusses the different approaches proposed as a solution to fire emergency evacuation.

2 Literature Review

2.1 Building Information Modelling (BIM)

In 2014, Wang et al., highlighted how to employ BIM as a detailed building information supplier, to work with virtual reality, together building an adaptable immersive serious game environment to provide real - time guidance on fire evacuation. This idea utilized an adjustable A* algorithm and layered grid graph for responding towards a scenario of building emergency using a database of Apache, My SQL and PHP [4]. Ma, J., Jia, W., Zhang, J., proposed a BIM for guidance about three-dimensional building within the considered evacuation path. Through complete integration of virtual reality technology with BIM, the proposed system aimed at forming a management platform, through which evacuation drills become more convenient and management personnel can direct the rescue operation more accurately [5].

2.2 Agent-Based Modelling

The evacuation model proposed in [6] simulated a more realistic pedestrian/evacuee movement within a cell-based environment. By taking care that agents don't only move to an adjacent cell having lowest distance cost or the nearest node to final target for more than one node with the equal lowest cost, agents being forced to move to the same grid location is avoided by their modified algorithm, (by using priority queue flood fill and A* algorithm) enabling the pedestrian movement to be determined by step numbers and directions instead of the calculated costs.

Bakar et al., in [7] focused on the unpredictability that comes in human movement during fire emergency, due to panic behaviours, and therefore proposed a simulation model based on Agent-Based Simulation (ABS) and Social Force Simulation (SFS) Model to improve on fire evacuation modelling in a restricted space such as a building.

Richardson et al., suggested a model of micro as well as macro - pedestrian dynamics composed of a space-continuous agent based representation (micro - level) and a compressible continuum flow model (macro - level) in [8]. He also established, that there is a strong impact on evacuation time when actual number of people with surroundings knowledge falls below a certain threshold. Their simulations indicate that even in some cases, having environmental knowledge raises the risk of smoke and fire exposure, possibly because, alternatives other than the fastest exit route are not seriously considered.

2.3 Network-Optimization Based Algorithms for Fire Evacuation

Barnes et al., in [9] proposed graph based solution for fire evacuation, capable of incorporating 3D cases naturally, nodes are sensors of the network, but specialized nodes for isolated floors/exits are not used. $F_{u,v}$ is time taken for a hazard to spread from the sensor locations u to v; $R_{u,v}$ is time for a human to navigate from the sensor location of u to v. (these are Hazard weight and Navigation weight resp.)

Suppose at a moment, if a number of fire hazard locations are detected by the WSN, then a hazard time H_u for each graph's node, calculated by graph traversal, will be, as stated in Eq. (1), with u_0 hazardous,

$$H_u = \min\left\{\sum_{i=1}^{n-1} F_{u_i,u_{i+1}} : (u_0, ..u)\right\} \tag{1}$$

Calculation for a paths' safety can recursively be as, Eq. (2),

$$S((v_{exit})) = H_{V_{exit}} \ldots (\text{hazard time to reach exit}) \quad (2)$$

Also, if safety path p = (v_1,v_2,…v_{exit}) is known, below path ‘p’ in Eq. (3), has the safety value as stated in Eq. (4).

$$p = (v_0,\ v_1,\ v_2, \ldots v_{exit}) \quad (3)$$

$$S(p_1) = \min\{\ S(p) - R_{V_0,V_1}, H_{V_0}\} \quad (4)$$

By assuming that a building has a fire hazards sensing network is efficiently deployed, to detect fire in early stages, the model by Tabirca et al., in 2009 uses a dynamic navigation graph to monitor the fireside dynamics along with progress of evacuation, to make sure that evacuees keep safely sooner than the hazard. Instead of distributed approaches in [9], it creates a dynamic graph by centralized computation, where the arc weights change after some time contingent upon the fire hazard presence, the arc weight represents the anticipated time to travel alongside the arc and this fluctuates depending upon the time at which the arc is traversed with respect to the incoming danger. This study lays the proposition that the dynamic cost function in shortest dynamic path problem satisfies the FIFO rule, also calculates and ensure that safe transitions, that are, maximum amount of times one can safely delay at the start node, are finite. Additionally, that these safety values are decreasing over time is also established by this paper [10]. The dynamic model generates information estimated on the dynamics of the fire hazard; and then generates a set of dynamic weights of navigation $c^t(u,v)$ portraying the time required to actually walk between two neighboring locations u and v. Also, the model continues to generate a series of dynamic centrality indices that provide useful data on each node’s importance entire process of evacuation order.

2.4 Behavior Based Modelling of Crowd in Fire Emergency

From values based on experimental research, the variability factor, of physical abilities of standard occupants and people having permanent or temporary locomotion impairment, in a music festival area was accounted by their approximate unrestricted distribution of walking speed. This evacuation model, by Ronchi et al., in [11], incorporates these distributions in order to reproduce human behaviour during evacuation, for e.g. delay time distributions, etc. Individuals movement was replicated within Pathfinder by investigating the embedded multi-agent based continuous evacuation models to deliver estimates of the time curves for people-evacuation in connection to various evacuation scenarios. With quick responders’ evacuation overlapping, in the overall evacuation, route choice is simulated using the model’s default algorithm, which has a locally quickest path planning approach, i.e., courses/routes are positioned hierarchically utilizing nearby data about individuals’ location and exits’ queuing times.

Radianti et al., proposed a dynamic Bayesian network (DBN) based model which underpins crowd behaviour of distinct kinds during evacuation, and is predicated on studies of physical fire models, crowd psychology models, and corresponding flow models. Their proposed Crowd Evacuation Model is implemented with SMILE engine and simulated by GeNIe Modeler and is such that it keeps track of people's location, people's flow until their escape, and hazard development status at these locations, at consequent time steps [12]. In [13], Lu et al., captured anxiety's impacts on route opted for and ability to interact with psycho-logical features such as guidance and herding responses. This is achieved by using an optimization framework where the number of planning steps and values of psychological parameters are affected by anxiety. To validate their approach, anxiety levels have been manipulated by hazardous conditions and the lengths of planning horizon are assessed by comparing extracted route options with data in Virtual Reality experiments. Aiming to optimize the distribution and composition of the occupants, estimate strategies for evacuation, and consequentially increase the efficiency of evacuation, Hu et al., in 2018 studied influence by human and fire factors and by their interaction on an evacuation process, which was based on typical assumed exit choice strategies [14]. In a systematic view, they set fire to 50000-kJ/kg combustion value, and correspondingly the temperature, height, and CO and CO_2 concentrations of smoke layer for ignition room, corridor staircase were all assumed. To reflect the exit balance situation and efficiency of whole evacuation, they took the weighted value δ as the experiment index, expression of which is as stated in Eq. (5),

$$\delta = 0.8 * \frac{\text{required safety evac.time}}{\text{total evacuee number}} + 0.2 \times \text{occupant pass situation} \tag{5}$$

2.5 Multi-objective Optimization Based Approaches for Fire Evacuation

Shikhalev, D., Khabibulin, R., Wagoum, A., in 2014, in [15] formulated the optimization problem, constraint being, to minimize the following assumed criteria: 'information regarding usage of the current section', 'criterion of timeliness that leads away from routes where fire hazards could be reachable', and the 'relative physical length of the current section'. The problem was hence, to calculate the safest escape route for person N_1, N_2…, N_i from the starting positions m_1, m_2,…, m_i to the safety areas s_1, s_2,…, s_i. They used a safest path criterion φ as optimization, stated in Eq. (6),

$$\varphi = \sqrt{(\alpha.a_i)^2 + (\beta.b_i)^2 + (\gamma.l_i)^2} \tag{6}$$

Here weight coefficients α, β, γ at a_i, b_i, $l_i \rightarrow$ min, where i = 1,..,n. are added for importance regulation of the individual criterion. On calculating φ, determination of an optimal escape route is achieved using the Floyd Warschall algorithm, means of which are expressed below, stated in Eq. (7). Here, d_{ij}^{m} denotes shortest distance between vertices 'i' and 'j'; 'm' is the intermediate vertices between of the path.

$$d_{ij}^{m} = \min \left\{ d_{im}^{m-1} + d_{mj}^{m-1}, d_{ij}^{m-1} \right\} \tag{7}$$

Cisek and Kapalka, in [16], considered a queuing system concept, in an evacuation process simulation. Upon starting a simulation, current data from a movement sensing system will initiate an amount of people in it in individual nodes. In the process of moving of evacuees from a given room to a door, time at which each person in i^{th} room arrives at j^{th} room's door is calculated based on Eq. (8),

$$T_{ij}^{n} = T_i + \frac{L_{ij}}{v_i * P_i(0)} * n \tag{8}$$

Here 'n' denotes person's number, v denotes mean speed of movement within a room, P denotes number of individuals present there, 'L' defines travel distance. For entities migrating between rooms 'i', 'j', the time to attain then the next doors, is determined by the fraction $(L_{i\ j\ k})/(v_j)$.

Another type of queuing system additionally considers possibility to include density - dependent changes in the pace of movement. Basically, the time F_{ij} between rooms to cross the doors is determined product of 'F' and 'W_{ij}', 'F' giving the assumed maximal flow of individuals, and 'W' denoting door width between rooms. To analyse the efficiency of their model, a series of simulation experiments was conducted for a selected building, which was assumed to be occupied by 450 people. They summarized the results to indicate that the evacuation time is cut shorter when the system of evacuation routing is put to use in situation where hazard is not taken into account. The evacuation time with guidance is longer in cases where a hazard is present; however, the forecasted death toll is smaller, particularly for people's uneven distribution in the endangered area [16].

2.6 Some Interdisciplinary Frameworks

Using artificial systems for testing prearranged emergency plans, parallel execution and computational experiments, Hu et al., [17] in 2014 proposed an approach based on cyber physical - social systems (CPSS), in which it is possible to fully connect with building structures, fire scenarios, safety managers and evacuees. According to this study, construction of data-driven parallel mechanisms implemented between artificial and physical evacuation systems, can potentially help to achieve real time guidance for evacuation.

Liu et al., assumed deployed sensors for determination of state whether a considered building area is blocked or transitable. A communication network carries the sensor information and the central server aggregates it. Here, using a collection of those transitable areas, calculation of evacuation paths, is done on the A* algorithm basis. The central server computes in real-time, the evacuation route, and again through the communication network, sends the recommendation information to the evacuee/occupant. For validation at model level, their fire model assumed fire with constant spreading direction and speed. Their simulation results showed that routing using a safety margin distance has the potential to increase the success ratio for evacuation during spreading fire scenario [18].

3 Challenging Issues in Existing Systems

3.1 Complexity of Decision-Making

Modelling of fire emergency management can be done as a problem of optimization (can be of a nonlinear combinatorial nature) in order to allocate resources to tasks thereby minimizing overall costs also. Because classical optimization algorithms can be easily get stuck in local minima and exact solutions, and can be computationally expensive as well as time-consuming, therefore, meta-heuristics algorithms inspired by natural and artificial intelligence have motivated considerable research.

Although heuristic algorithms cannot guarantee that the optimal solution will be discovered, they can in polynomial time find a suboptimal solution. Li et al., in [19] during 2018 researched on evacuation for fire in a library of a University, concluding that dense population and evacuation channels which are relatively narrow, lead to congestion, due to which velocity of safe evacuation is greatly reduced. For their case, exit was the first to attain the dangerous state. Moreover, it was observed that hazardous area's direction was paradoxically the direction of safe evacuation. Also, people quickly flocked on the exit causing congestion. Therefore, route indicator, emergency exit and lighting, along with fire alarm system required improvement.

3.2 Route Searching

Available static evacuation plans in most buildings possess drawbacks when environment/conditions for evacuation, change during severe fires. Moreover, evacuees or end-users with a disability, due to limitations in their movement, may need the safest evacuation route instead of the shortest. Therefore, it is necessary to further investigate more onto the choice of precise and reliable path finding algorithms for their type of situation.

3.3 Communication Delays and Network Security

Majumder et al., showed that their entire system which was an IOT based model currently takes 25 to 40 s from sensing the fire to correctly updating the website. Using a dedicated server for hub processing could significantly improve speed [20]. Hence, a need to incorporate the support of a robust network coupled with adequate data transmission is felt in most of the approaches reviewed. Wireless sensor networks are usable, but their deployment is particularly prone to denial of service and denial of sleep attacks due to dependency on computing power, memory, bandwidth and battery power. Also for approaches which consider centralized mechanisms for route calculation, need higher speed data transmission for overall shrinking of recommendation updation to the concerned evacuee.

4 Conclusion

In this paper, we discuss different approaches developed for fire emergency management and the challenging issues that need to be addressed to enable the requirements for these approaches. Decision - making complexity, optimization of algorithms, route search, network security, and energy - efficient management are key research issues for any emergency management evacuation. In addition, multidisciplinary collaborative research is highly needed to design future fire evacuation management systems due to requirement of including technologically different elements in system design, followed by interface. Finally, we conclude by highlighting below, a few directions for future research in this area.

4.1 Updation of Dynamic Signs with Enhanced Frequency

While the objective of formulated algorithms for evacuation would ultimately be of their integration into an evacuation system using dynamic indicators to provide recommendations/instructions of safe directions during evacuation but theoretically different considerations come into picture. More frequently upgrading the dynamic signs provide sharper command over the evacuees, allowing the system to approach an optimal solution more closely. However, potentially allowing the recommendations to update directions too often lowers the evacuee compliance, because evacuees observe the switching directions/signs as they reach them, it may confuse them regarding which specific instructions to obey. Therefore, the update rate should be a balance that delivers adequate and decent performance while maintaining the evacuee's compliance. Also, the lack of information about the evacuees who actually respond to dynamic and predicted signs would deter the research from reaching a final conclusion.

4.2 Performance Gauged During Low-Occupancy Scenarios

For scenarios of high - evacuee headcount, several systems tend to perform better. Evacuating crowded buildings takes longer, and this allows the signs to perform more updates or time steps, thus better distributing the evacuees across different paths. On the one hand, desirable feature can be improved performance in crowded buildings as fire scenarios inherently carry a higher risk. On the other hand, the system developer's initial objective can be to design a system that minimizes the evacuation time regardless of the building's distribution and number of evacuees. However, as the number of evacuees decreases, congestion is increasingly becomes a predominant factor. This inherently makes it far less relevant to a dynamic congestion management system. For systems which aim at Congestion - Optimization, will have a low operating when limit headcount evacuee is considered.

4.3 Performance of Simulation Models

In short, simulation of personal actions in evacuation being complex, till now, there is no single model that can fully resolve the different aspects of evacuation behavior. However, it can be anticipated that more details will be contained in the future evacuation model, moving towards prediction of individual behavior, simulation of large populations and complex characteristics along with managing the complex interdependencies between the infrastructure, environment and human behavior. A proper, relevant criterion for validation of decision making and calculated route also needs to be investigated.

5 Future Research Plan

For widespread infrastructures, since it would be difficult for its facility users or visitors to navigate from one location to the other, and this issue could aggravate in the times of emergency; also, GPS-based navigation does not work indoors, hence there arises a need to have any application in place to guide users with the shortest route within the facility, based on floor maps, to their destination; thereby enabling the users to exit on time, safely. Also for emergency of fire, management should be empowered with high speed ethernet solutions. So, the future aim is to study on embedded aspect, that is, hardware solution, that can be provided to this problem. The above different approaches given by various researchers in the past, can't just be compared for their superiority, but their collective working on multicore processor architechture, is aimed to be developed for more dependable outcomes.

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