An Agent-based Model for Emergency Evacuation from a Multi-floor Building

Extended Abstract

Xiaoyan Zhang
Newcastle University
Newcastle upon Tyne, United Kingdom
x.zhang110@newcastle.ac.uk

Graham Coates
Newcastle University
Newcastle upon Tyne, United Kingdom
graham.coates1@newcastle.ac.uk

Sarah Dunn
Newcastle University
Newcastle upon Tyne, United Kingdom
sarah.dunn@newcastle.ac.uk

Jean Hall
Newcastle University
Newcastle upon Tyne, United Kingdom
jean.hall@newcastle.ac.uk

ABSTRACT

This extended abstract presents an agent-based model to enable simulations to be performed of evacuations from a multi-floor building, thus including the movement in staircases. In the model, agents select exits and staircases based on familiarity level with the building layout, spatial distance to exits, preference to evacuate via the main entrance/exit, and visibility of exits and staircases. The agent-based model has been validated using the empirical findings of an evacuation drill in the staircase of a four-floor building. The novel contribution of this research is the development of a more realistic agent-based model aimed at providing decision support for the layout design of buildings and evacuation behavioral management in emergency evacuation. That is, the agent-based model mimics people's natural movement in staircases, and involves agents' exit and staircase selection, and movement on floors. Simulations have been performed to investigate the effect on evacuation time of (i) number of agents and their familiarity with the building layout, and (ii) exit selection of agents.

KEYWORDS

Emergency Evacuation; Agent-based Modeling and Simulation; Multi-floor Building

ACM Reference Format:

Xiaoyan Zhang, Graham Coates, Sarah Dunn, and Jean Hall. 2022. An Agent-based Model for Emergency Evacuation from a Multi-floor Building: Extended Abstract. In *Proc. of the 21st International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2022), Online, May 9–13, 2022,* IFAAMAS, 3 pages.

1 INTRODUCTION

Emergency situations in which evacuation is necessary can occur in multi-floor buildings, which may lead to serious casualties and even fatalities. There are many reported egress-related disasters in history [5]. In multi-floor buildings, staircases are common components and the movement in staircases may form a considerable part of the overall evacuation process [4]. In order to ensure the safety of people in emergency situations, it is important to study the emergency evacuation from multi-floor buildings, especially those involving staircases. It has been recognized that computational models can be used to study emergency evacuation in multi-floor buildings [2], in which agent-based models have gained increasing attention [7] because they provide a natural and real-world description of a system [1]. This extended abstract reports on the development of an agent-based model for emergency evacuation in multi-floor university buildings, which focuses on the movement in staircases and incorporates exit and staircase selection of agents.

2 AGENT-BASED MODEL

Due to the focus of this extended abstract, the agent movement in staircases and the agents' decision-making regarding exit and staircases selection are described in this section.

2.1 Agent Movement

The basis of agent movement in this model is the 'stride' concept, which was first proposed in the Optimal Steps Model [9]. In staircases, the stride length is limited by the depth of a stair step [6]. People rarely take more than one stair step at a time and they do not use one stair step twice [8]. Further, it is observed that people hardly deviated from the straight line when other pedestrians were present. Thus, for an agent in the model presented in this paper, instead of moving its maximum stride (which could be two stair steps) downstairs or upstairs, the agent first checks if the area in front of it is fully or partially occupied by other agents. If it is not, the agent will move straight ahead to the next stair step. However, if it is, the agent can (i) wait at this time step, or (ii) check other areas on the stair step (overtake other agents) at this time step. If the agent determines to wait, then it will stay at the same location at this time step and re-apply the checking process at the next time step. Otherwise, the agent will check other possible points on next stair step. Note that the agents in this research are assigned with a probability to overtake other agents in order to simulate an evacuation in a more urgent situation.

2.2 Exit and Staircase Selection

In this research, the familiarity level is one factor that has an impact on the agents' exit and staircase selection. Each agent assigned with one of three values: (i) F = 1 indicates that the agent has knowledge

Proc. of the 21st International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2022), P. Faliszewski, V. Mascardi, C. Pelachaud, M.E. Taylor (eds.), May 9–13, 2022, Online.

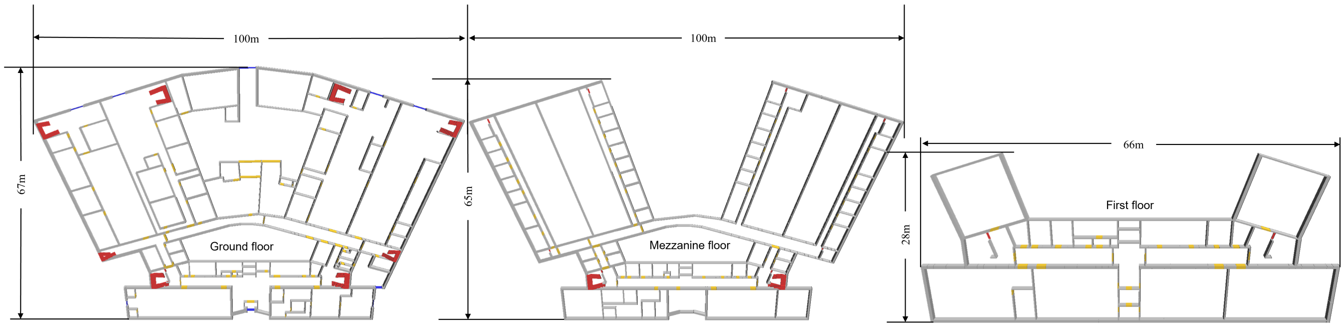

Figure 1: Layout of a three-floor building

of one exit, namely the entrance/exit through which it entered the building, and one staircase if the agent used a staircase when it entered the building; (ii) F = 2 indicates that the agent knows n_{KE} ($2 \leq n_{KE} \leq n_{TE} - 1$) exits and n_{KS} ($2 \leq n_{KS} \leq n_{TS} - 1$) staircases, in which n_{KE}, and n_{KS} represent the number of known exits and known staircases of the agent respectively, whereas n_{TE} and n_{TS} indicate the number of exits and staircases in this building respectively; and (iii) F = 3 indicates that the agent is aware of all the exits and staircases. These definitions of familiarity level enables agents to be assigned a range of known exits and staircases.

In terms of exit and staircase selection, at the beginning of an evacuation simulation, agents with familiarity level F = 1 select the known exit, and/or the known staircase to evacuate to the exterior of the building. For agents with familiarity level F = 2, each agent may select (i) the main entrance/exit to move to, with a probability p_{ME} or (ii) the closest exit to move to, with a probability $p_CE = 1 - p_{ME}$. Any agent with familiarity level F = 2 has a probability of using the main entrance/exit to evacuate even if it knows other exits because in real life evacuation situations people are reluctant to evacuate via the exits they do not use in normal situations (e.g. emergency exits) [3]. If the chosen exit of an agent with familiarity level F = 2 is located on another floor, the agent will select the staircase from those it has knowledge of based on the total moving distance from its location to the staircase and then to the chosen exit being the shortest. During the evacuation simulation, agents with familiarity level F = 1 and F = 2 may encounter a visible but unfamiliar exit or staircase. These agents have a probability p_{VUE} to use the visible but unfamiliar exit or staircase. In terms of agents with familiarity level F = 3, each agent selects the closest exit to move to, using the shortest route to leave the building. While taking the shortest route, the agent may use a staircase.

3 VALIDATION FOR STAIRCASE EVACUATION USING EMPIRICAL FINDINGS

The agent-based model has been compared with the empirical findings of Xu and Song (2009) [11], who conducted an evacuation drill in the staircase of a four-floor building. Their research is selected because the evacuation drill occurred in a building with multiple floors, which is relevant to the modelling environment of this paper. In addition, their paper provides necessary details to enable the validation.

Compared to the evacuation time in the drill [11], 88 secs, the average evacuation time of the simulation in this research is 85.15 secs, which is 2.85 secs (3.24%) shorter. In addition to evacuation time, crowd dynamic related behavior data has been validated: (i) total number of evacuated agents against time (ii) number of agents that enter the staircase against time; (iii) number of agents that leave the staircase against time; (iv) number of agents in the staircase against time for the staircase between all adjacent floors. The difference between our simulation results and published drill results [11] in relation to (i), (ii), (iii) and (iv) mentioned above ranges from 2.6% to 7.4% in most cases.

4 SIMULATION AND DISCUSSION

For the case study, the agent-based evacuations modeled and simulated occur in a three-floor building, based on the layout of the ground floor, mezzanine floor, and first floor in the Stephenson Building at Newcastle University, UK (see Figure 1). Note that the scale of the first floor is larger than that of the ground floor and mezzanine floor in order to present the floor plan clearly. In Figure 1, exits, internal doors, walls and staircases are colored blue, yellow, grey, and red respectively. In terms of the stairs that connect adjacent floors, on the lower floor all the stairs are indicated and on the upper floor the first steps of the stairs are shown.

Sixty simulations experiments have been defined and performed to investigate the effect on evacuation time of (i) number of agents and their familiarity, and (ii) exit selection of agents. From the simulation results, it is known that for building emergency evacuation, people are likely to have a dominant impact on the whole evacuation, who (i) do not evacuate the building via the closest exit due to low familiarity with the spatial layout or the preference to evacuate via the main entrance/exit; and (ii) move at a slow speed. These people deserve the attention of practitioners. Specifically, at the design phrase of a building, all exits should be distributed uniformly in the building so that each location within the building is not far from at least one exit. However, it is not usually the case that people evacuate the building as expected by the building designers. During the use of a building, people based in a building should be trained to know all the exits and evacuate the building via the closest one. Also, authority staff can help people new to a building to evacuate more efficiently.

REFERENCES

[1] Benigno Aguirre, Sherif El-Tawil, Eric Best, Kimberly B. Gill, and Vladimir Fedorov. 2011. Contributions of social science to agent-based models of building evacuation. *Contemporary Social Science* 6, 3 (2011), 415–432.
[2] Gabriele Bernardini. 2017. *Fire Safety of Historical Buildings. Traditional Versus Innovative "Behavioural Design" Solutions by Using Wayfinding Systems* (1st ed.). Springer International Publishing, Cham, Switzerland.
[3] Rose Challenger, Chris W. Clegg, and Mark A. Robinson. 2009. *Understanding Crowd Behaviours: documents*. Technical Report.
[4] Steve Gwynne and Karen Boyce. 2016. *Engineering Data*. Springer New York, New York, NY, 2429–2551.
[5] Yu-Hsiang Hsieh, Ka Ming Ngai, Jr. Burkle, Frederick M, and Edbert B Hsu. 2009. Epidemiological characteristics of human stampedes. *Disaster Med Public Health Prep* 3, 4 (2009), 217–23.
[6] Gerta Köster, Daniel Lehmberg, and Felix Dietrich. 2016. Is Slowing Down Enough to Model Movement on Stairs?. In *Traffic and Granular Flow '15*. Springer International Publishing, Cham, 35–42.
[7] Charles M. Macal and Michael J. North. 2009. Agent-based modeling and simulation. In *Proceedings of the 2009 Winter Simulation Conference (WSC)*. Winter Simulation Conference, Austin, 86–98.
[8] Michael J. Seitz, Felix Dietrich, and Gerta Köster. 2014. A Study of Pedestrian Stepping Behaviour for Crowd Simulation. *Transportation Research Procedia* 2 (2014), 282–290.
[9] Michael J. Seitz and Gerta Köster. 2012. Natural discretization of pedestrian movement in continuous space. *Physical Review E* 86, 4 (2012), 046108.
[10] Isabella von Sivers, Anne Templeton, Florian Künzner, Gerta Köster, John Drury, Andrew O. Philippides, Tobias Neckel, and Hans Joachim Bungartz. 2016. Modelling social identification and helping in evacuation simulation. *Safety Science* 89 (2016), 288–300.
[11] Xuan Xu and Weiguo Song. 2009. Staircase evacuation modeling and its comparison with an egress drill. *Building and Environment* 44, 5 (2009), 1039–1046.