Modified Navigation Algorithms in Agent-Based Modelling for Fire Evacuation Simulation

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1. Introduction

Hazardous events which threaten people's lives force an immediate movement of people wanting to escape from a dangerous area. In their review of man-made and natural disasters, Wolshon *et al*. (2005) listed a number of hazards requiring evacuation and pointed out that some evacuations could only be carried out after disasters occur. Therefore, people need to run through evacuation drills to learn evacuation skills and to ensure they are familiar with the environment. However, evacuation drills cannot realistically represent a real emergency situation and people may be injured during the practices. To overcome these issues, evacuation models are useful for simulating these hazardous situations. Models remove the risk to human safety that may be present during drills, and generate efficient evacuation routes for emergency plans. One of the common modelling approaches is agent-based modelling; an agent-based model is a computational model using virtual agents to simulate independent actions, social interactions, adaptive processes, and goal-directed navigations. This type of evacuation model was presented to study inter-relationships between individuals and groups' behaviours (Musse and Thalmann 1997), steering behaviour (Reynolds 1999), and the behaviour of individuals with disabilities (Christensen and Sasaki 2008).

The most common hazardous events in the built environment are related to fire (Federal Emergency Management Agency 2010) and this research considers agent-based modelling in the context of fire evacuation. Specifically, two aspects are examined: human evacuation behaviour based on fire investigation reports (for more details, see Roan *et al*. 2011) and navigation algorithms, which are described here.

Two approaches to such modelling can be identified – continuous space and grid-based. Simulating a high density of occupants moving around in continuous space models such as Social Force (Helbing and Molnár 1995) can cause issues as agents are restricted to moving around to avoid pedestrians and obstacles rather than being allowed to overlap. In reality, according to fire reports, occupants sometimes step over others and cause serious stampedes in real fire situations. Therefore, our model divides the space into regular grid cells and allows agents to overlap in extreme situations.

This paper focuses on modified navigation approaches to address one of the challenges in grid-based models – route selection, simulating pedestrian movement using multiple path selections rather than a fixed route in order to model behaviour in a more realistic manner.

2. Modified Navigation Algorithms

The shortest path search approach and potential field approach are commonly used for navigation in agent-based models (Overmars *et al*. 2008, Bennewitz *et al*. 2002). The *shortest path search approach* is used for finding a path between two nodes based on a weighted graph (Foudil 2009), and one of the typical algorithms – *A* algorithm*, which is a generalisation of Dijkstra's algorithm (Dijkstra 1959, Hart *et al*. 1968), uses a distance-plus-cost heuristic function to determine a list of nodes for an optimal route. The *potential field approach* uses potential distance calculated between coordinates and predefined waypoints (Pelechano *et al*. 2007, Koh *et al*. 2008). An example of this - the *priority queue flood fill algorithm* calculates distance costs by selecting the lowest distance cost as a prioritised node.

Existing models, such as EXODUS[1] model (Galea 1998), simulate interaction between pedestrians and environment in cell-based models but result in unrealistic movement with agents moving at 45 degrees as their first movement and changing directions until they meet an obstacle (Pelechano and Malkawi 2008). Figure 1 shows the effect of the movement from STEPS[2] software (Mott MacDonald 2009).

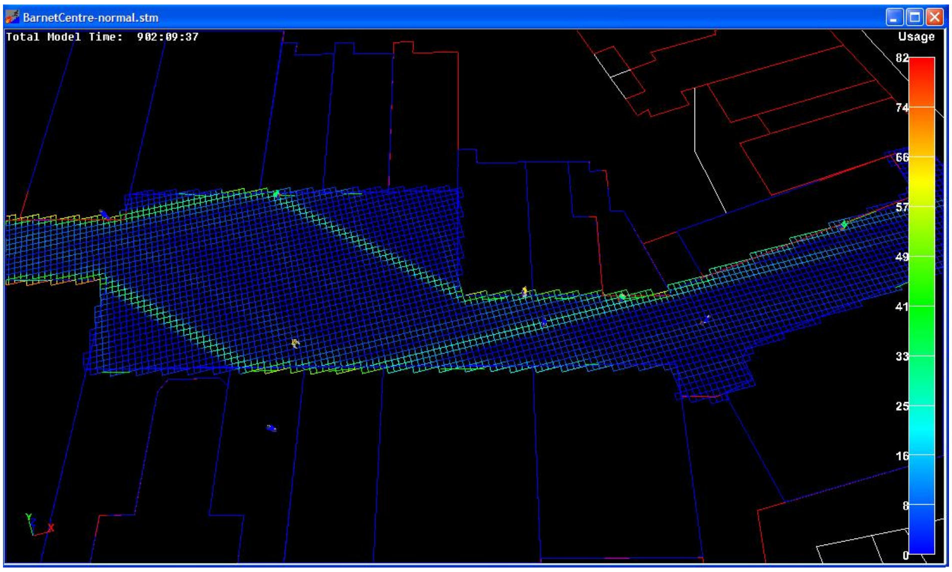

Figure 1. A frequency of grid usage based on a potential map shows the trajectory of pedestrian movement.

In general, the priority queue flood fill algorithm requires that agents always move to an adjacent cell with the lowest distance cost, and the A* algorithm selects the nearest node to final target if it calculates more than one node with the same lowest cost. Therefore, both methods return a fixed route selection that force agents to move towards

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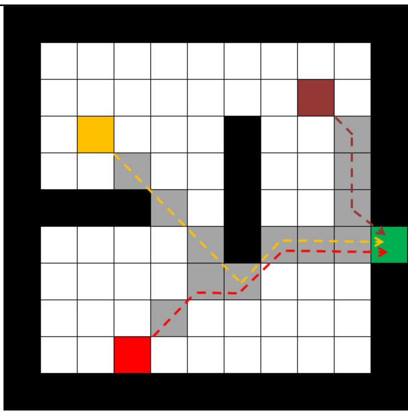
[1] EXODUS is developed by the Fire Safety Engineering Group at the University of Greenwich. The model is based on a set of sub models for evacuation simulations and pedestrian dynamics/circulation analysis.

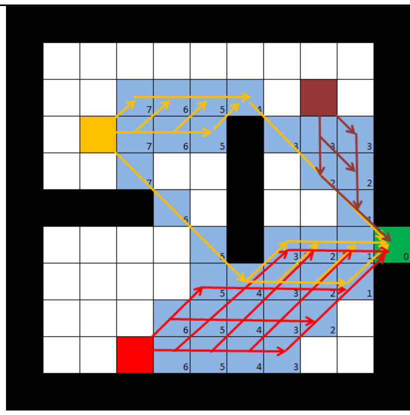
[2] STEPS is a simulation tool developed by Mott MacDonald, UK. It is used to simulate pedestrian movement under a normal or emergency condition.

the same grid location (Foudil 2009, Overmars *et al.* 2008). Our evacuation model addresses these issues to simulate a more realistic pedestrian movement in a cell-based environment. We propose a modified algorithm which includes additional steps and directions when calculating distance cost, so pedestrian movement is determined by step numbers and directions instead of the calculated costs.

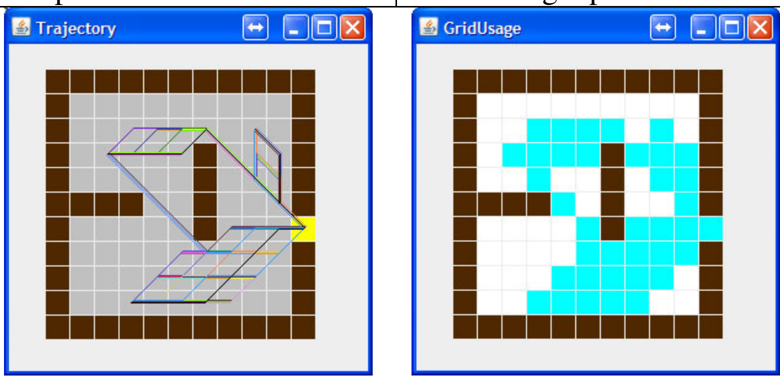
To validate the adapted versions of the A* and priority queue flood fill algorithms, a test scenario was developed (Figure 2). The potential field approach now calculates distance costs from an exit to every cell and creates a potential table, and the shortest path search approach calculates costs from each person's location to the destination. In both cases, after calculating a full list of costs, a path is identified in terms of step numbers and directions from an exit to the occupant location to ensure pedestrian can reach the final target. Unlike the standard approach (Figure 2-a), multiple start-to-finish routes may be considered (Figure 2-b) - the result on the test scenario in Figure 2-c shows 8 potential routes for the yellow agent, 3 potential routes for the brown agent, and the red agent has 34 potential routes from the starting point to the exit. These paths are more flexible compared to one fixed route from the standard calculations.



a. Fixed route calculated by the standard A* and priority queue flood fill algorithms. The grey area shows individuals' potential movement area.



b. Additional steps (1, 2…etc) and directions (arrows) from the modified algorithms. The blue area shows larger potential movement area.



c. Agents' trajectories and grid usage displayed from our evacuation model after 100 runs. (one colour of trajectories represent their routes in a run; grid usage in blue colour shows their potential movement area)

Figure 2. Standard and modified navigation algorithms in a test scenario.

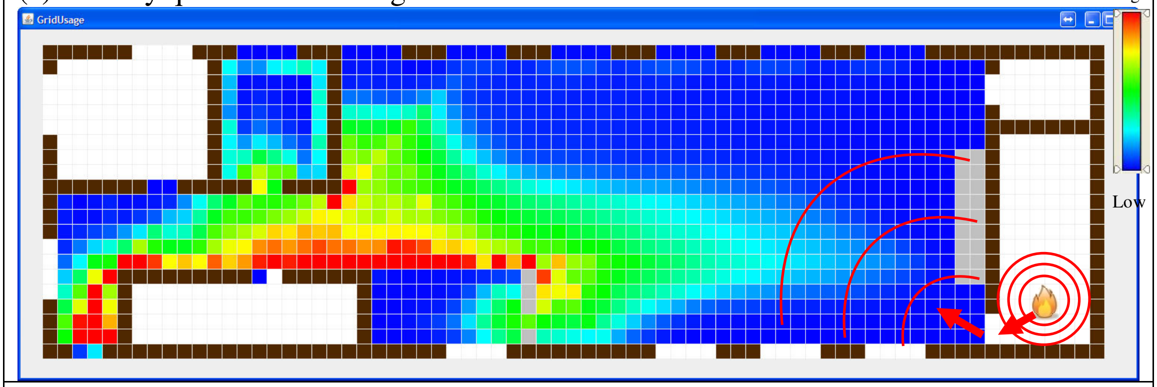
3. Implementation and Results

A key limitation of the majority of existing building evacuation models on fire, such as the Gothenburg Disco fire simulation (Jiang *et al*. 2001), is that they only simulate agents evacuating from standard building exits. However, as evidenced by our review of fire investigation reports (Best and Swartz 1978, Yates 1991), people sometimes hide in a room or stand at windows waiting for rescue. Evacuation behaviour has been implemented in our model on the basis of a review of twenty fire investigation reports to represent a more complete and realistic test.

A 71x21 grid scenario (grid size: 0.5m^2) was built based on Comeau and Duval's report (2000) using JAVA programming with an agent-based toolkit, Repast Simphony (North *et al*. 2007). This report recorded a fire incident which resulted in 63 deaths and 180 injuries in a nightclub in Gothenburg, Sweden on 28 October 1998. The officials estimated that there were more than 400 occupants in the dance hall, whereas the building was only permitted 150 people at that time. There were two main exits which could allow people out of the dance hall, but the fire started at the southeast stairway and thus this exit was not able to be used during the evacuation. In addition, security bars were installed across the south side windows and three rooms were locked to avoid occupants entering during the party.

The simulation starts from a fire alarm that forces *pedestrian agents* to evacuate towards the main entrance where they entered. At this stage, they move in an orderly manner and form a queue at the exit. When the first *pedestrian* discovers the smoke, *pedestrians* communicate to warn each other of this hazard situation, and then their behaviour changes to panic. Therefore, *pedestrians* recalculate their routes according to individual own decisions, for example, rushing to an exit nearby, evacuating through alternative exits, seeking shelter in a room, or calling for helps from a window. In addition, other types of agents also influence pedestrian movement – *pedestrians* will not move towards the *fire*; *pedestrians* will faint after they inhale a specific amount of *smoke,* and they either die or are rescued by fire-fighters later; a *pedestrian* who discovers another *pedestrian* lying on the floor will chose to go around or step over the body; *exit agents* control pedestrian flow so that *pedestrians* move more slowly if too many agents rush to one exit. Figure 3 display grid usages of 400 agents' movement calculated by the two modified algorithms after 100 runs, and it shows the difference in tracking tendencies – agents tend to move in a diagonal direction and walk along the wall using the potential field approach, whereas in the shortest path search approach agents move straight toward the exit.

(a) Priority queue flood fill algorithm



(b) A* algorithm

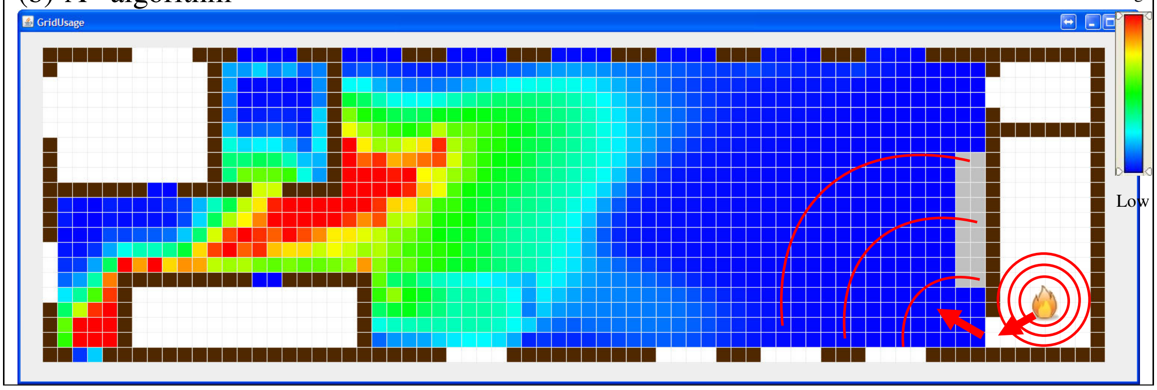


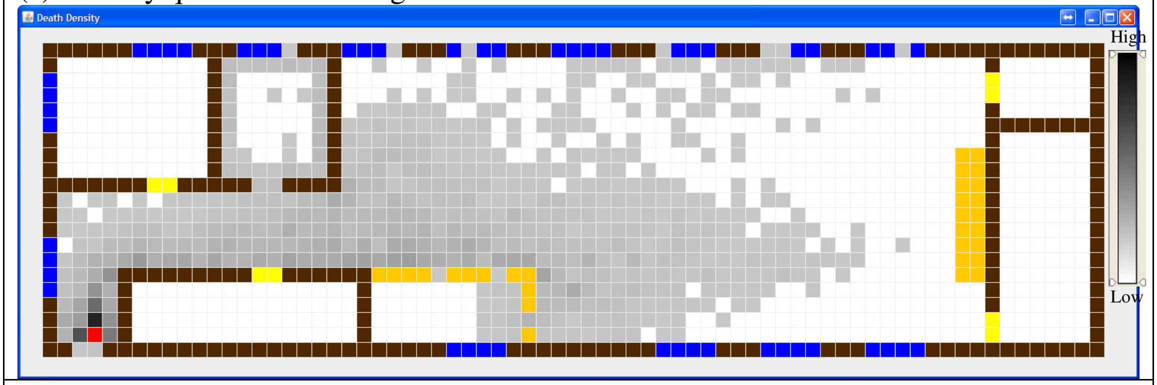
Figure 3. Grid usage maps of 400 agents' movement after 100 runs. The main entrance is at the south-west corner; some rooms and windows were locked, so occupants could not access them during the evacuation (white cells)

4. Conclusion and Further Work

Pedestrian movement, which is determined as a combination of modified navigation algorithms and pedestrian behaviour, influences overall evacuation time during the simulation. This paper presents modified algorithms to overcome issues with existing agent-based evacuation models in which agents are often routed to the same destination cell. Additionally, our evacuation behaviour, which is based on fire investigation reports, simulates a more realistic representation of egress selection. With the improvement of navigation calculation and behaviour determination, the model results an increasing accuracy of total evacuation time.

However, additional factors (such as individual height, gender, education level, group behaviour, pre-evacuation activities and location), which might influence individuals selecting egress routes, are not included in this stage of the model. Furthermore, this model simplifies smoke spread as having regular speed and movement which also influences the result. As shown in Figure 4, the model does not always results the correct location of deaths compared to the records in the selected fire report – in the fire report 43 bodies appeared around the main entrance and other 20 were found in the shelter room. Therefore, additional research into fire/smoke behaviour, how fire/smoke spreads through the space, how furniture influences the burning of fire and pedestrian movement, and how people inhale smoke should also take into consideration.

(a) Priority queue flood fill algorithm



(b) A* algorithm

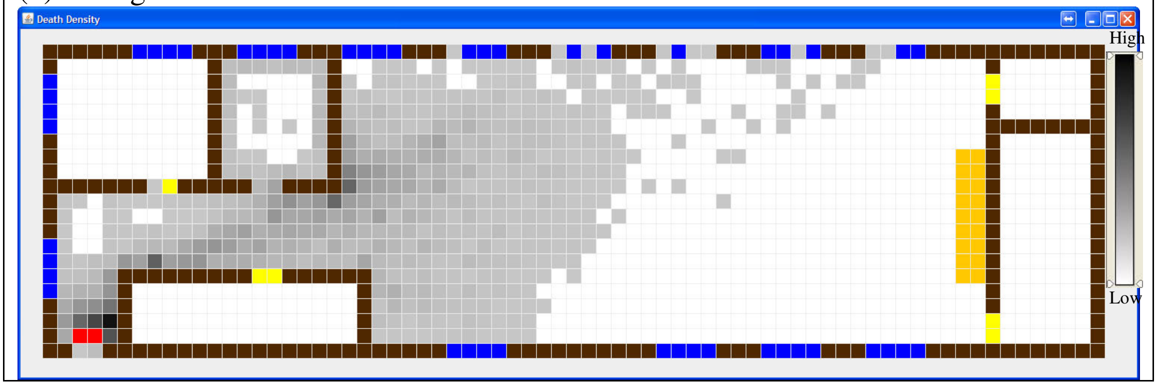


Figure 4. Percentage of death location in 100 simulations (red: very high possibilities where casualties appear).

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