Agent-based Modelling and Simulation for Lecture Theatre Emergency Evacuation

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ABSTRACT

This paper presents an overview of ongoing research into the implementation of an agent-based model aimed at providing decision support for the layout design of lecture theatres and human behavioural management in emergency evacuation. The model enables the spatial layout of lecture theatres to be configured and incorporates agent behaviours at the basic movement and individual level. In terms of individual behaviours, agents can be competitive, cooperative, climb obstacles (e.g. seating and desks) and fall down. Two cases are investigated to evaluate the effects of different exit locations in lecture theatres and competitive behaviour of agents on evacuation efficiency in multiple scenarios.

Keywords

Emergency evacuation, agent-based modelling and simulation

INTRODUCTION

Emergency situations in which evacuation is necessary can occur in locations with highly dense crowds of people, which may lead to serious casualties and even fatalities. There are many reported events in which emergency egress has resulted in injuries to people and loss of lives. For example, 8 students were killed and another 26 were injured in a stampede in a school stairwell in Hunan province, central China (BBC News, 2009). In this incident, about 400 students made for one narrow stairway after evening classes when one fell, setting off the crush. Therefore, emergency evacuation is particularly crucial in emergency and safety management, and in locations with a capacity for high occupancy.

Preparing and performing field emergency evacuation experiments can be expensive and time consuming with the consequence that only a few scenarios are able to be considered. Computer simulation is a cost-effective and safe means to assess egress performance with the ability to consider multiple 'what-if' scenarios (Chu et al., 2013; Wagner and Agrawal, 2013). Furthermore, complex human behaviour is difficult to model in emergency evacuation situations. Agent-based simulation has been used to study crowd evacuation in various situations due to its ability to replicate and assess human behaviour in evacuation scenarios (Fang et al., 2016; Tan et al., 2014; Chu et al., 2013; Pan et al., 2006; Wagner and Agrawal, 2014; Wang et al., 2015; Sun and Li, 2013; Xie et al., 2016). Although agent-based modelling and simulation has been used in current research, there is still a lack of realistic human behaviours modelled.

The ongoing research reported in this paper aims to develop an agent-based modelling and simulation system, which provides decision support for both the layout design of lecture theatres and human behavioural management in emergency evacuation. In terms of novel contribution, the ongoing research provides an agent-based model that is specifically designed for evacuation modelling from lecture theatres in which a number of internal obstacles (desks and seats) are located along with a high density of students. Furthermore, the integrated framework being developed and implemented incorporates realistic human behaviour and enables layout design.

RELATED WORK

A number of evacuation simulation models has been proposed (Bouzat and Kuperman, 2014; Chu et al., 2013; Ehtamo et al., 2010; Fang et al., 2016; Joo et al., 2013; Lu et al., 2016; Mesmer and Bloebaum, 2014; Pan, 2006; Song et al., 2016; Sun and Li, 2013; Tan et al., 2014; Wagner and Agrawal, 2014; Wang et al., 2015; Zheng and Cheng, 2011; Xie et al., 2016; Xie and Xue, 2011). According to the hierarchical layers of agent behaviour in evacuation models, these models can be classified into four categories, namely basic movements, individual behaviour, group behaviour and crowd behaviour.

The first category of models focus primarily on basic evacuation movements such as collision avoidance, exit detection and exit seeking. The bulk of published models fall within this category and often make assumptions and simplifications about agent behaviours such as simplifying the evacuation process into the movement of occupants from their initial positions to the outside of the building without considering behaviours such as competitive behaviour that may delay evacuation (Kuligowski, 2008). An affordance-based model assumes that the agent-based simulation framework considers only perception-based action, which implies the ecological properties of affordance and effectivity, rather than the social factors that might affect decision making (Joo et al., 2013). Two models mainly concentrate on the spatial aspect of evacuation while high level behaviours are not taken into account (Wagner and Agrawal, 2014; Tan et al., 2014). Wagner and Agrawal present an agent-based simulation system for crowd evacuation of concert venues under a fire disaster, which allows for user definition of the layout and structure of the concert venue (Wagner and Agrawal, 2014). Tan et al. develop a grid graph-based model where potential escape routes from each node could be analyzed through GIS functions of network analysis considering both the spatial structure and route capacity (Tan et al., 2014).

Individual behaviours are usually developed in models according to personal state such as (1) competitive (also referred to as impatient (Heliövaara et al., 2013), defect (Bouzat and Kuperman, 2013) and cooperative (also known as patient (Heliövaara et al., 2013) or yielding (Xie and Xue, 2011)) behaviour depending on stress level (Pan 2006, Fang et al. 2016) or bounded rationality (Heliövaara et al., 2013; Zheng and Chen, 2011, Bouzat and Kuperman, 2014; Song et al. 2016; Xie and Xue, 2011) or panic (Wang et al., 2015) and (2) exit choice where herding behaviour occurs based on degree of uncertainty (Pan, 2006) or exit choice relying on bounded rationality (Ehtamo et al., 2009; Mesmer and Bloebaum, 2014). In evacuation modelling, based on game theory, a number of researchers assume that agents evaluate all the available options and select the one with maximum utility (Ehtamo et al., 2009; Heliövaara et al., 2013; Mesmer and Bloebaum, 2014; Zheng and Chen, 2011, Bouzat and Kuperman, 2013; Song et al. 2016; Xie and Xue, 2011). For example, Ehtamo et al. assume that agents update their game strategies of exit choice based on their best response functions in a myopic manner (Ehtamo et al., 2009). Mesmer and Bloebaum develop a unique utility function based on energy expenditure for game strategies of exit alternative selection (Mesmer and Bloebaum, 2014). Four models make an assumption that each agent has two possible game strategies of play that lead to competitive and cooperative behaviour and agents adopt the strategy that would give them the highest payoff (Heliövaara et al., 2013; Zheng and Chen, 2011, Bouzat and Kuperman, 2013; Xie and Xue, 2011). Song et al. present game strategies for pedestrians combined with analyzing the reasons why agents choose to be competitive or cooperate combining with human emotions such as sympathy. Other researchers suppose that agents will behave in a competitive or cooperative manner given their level of mental stress (Pan, 2006, Fang et al. 2016) or panic state (Wang et al., 2015). Herding behaviour principally resulted from uncertainty associated with having insufficient information regarding what to do, thus resulting in them tending to follow the actions of others (Pan, 2006).

Agent behaviours simplified to individual level without considering group influence lacks realism as in the real world most people prefer to associate themselves with others in small groups (Xie et al., 2016). Based on Fang's work, there are two kinds of groups, namely social groups established by pre-existing relationships and informal groups established by informal and temporary relationships (Fang et al., 2016). Fang et al. propose that both groups can have a leader; however the leader-follower model in informal groups is temporary. There are other models concentrating on the implementation of social group behaviour (Chu et al., 2013; Lu et al., 2016; Xie et al., 2016). Chu et al. develops three group behaviours, namely group leader following, group member following and group member seeking (Chu et al., 2013). Lu et al. and Xie et al. both agree that group behaviours include staying together with group members and backtracking to search for lost group members (Lu et al., 2016; Xie et al., 2016). Lu et al. assume that the group leader may stop with a probability to wait for the other group members to return within a period of time (Lu et al., 2016). Xie et al. suppose that it is more reasonable to go back to search instead of waiting at some fixed position (Xie et al., 2016). In addition, in Xie et al.'s model, agents stay closer to socially intimate group members instead of simply moving to the so-called "group center".

At crowd level, agent behaviours are usually influenced by crowd density and velocity around an agent. Chu et al. use a navigation crowd density parameter to define the maximum crowd density in which agents can choose to execute individual and group behaviours (Chu et al., 2013). When the surrounding crowd density exceeds the navigation crowd density, other agents would give access priority to the agent with higher social order (Drury et.

al., 2009) by allowing the individual agent to pass through; therefore the agent with higher social order can navigate a congested area more easily. Fang et al. develop besieger-in-crowd behaviour which means an agent stuck in a slow-moving dense crowd and following the agent directly in front cannot behave competitively (Fang et al. 2016).

PRELIMINARY AGENT-BASED MODEL

Overview

The agent-based model under development is specifically designed for lecture theatres in which a number of obstacles (desks and seats) are located along with a high-density of students. The layout of obstacles and behaviours of students in a lecture theatre may negatively contribute to evacuation efficiency. Therefore, when modelling emergency evacuation, it is especially important to take into account both spatial layout and agent behaviours. One aim of this research is to estimate the effect of the internal arrangement and layout of lecture theatres on evacuation efficiency. Multiple scenarios can be simulated (e.g., wider aisles, additional exits, and so on). Another aim of the research is to measure the effect of agent behaviours on evacuation efficiency. At the early stage of the research, agent behaviours have focused on basic movement and individual level. The individual agent behaviours discussed in this paper are competitive, cooperative, climbing and falling down. In addition, conflicts between agents caused by competitive behaviour are represented.

Spatial Layout of the Environment

The layout of a lecture theatre is constructed in a grid environment with each cell being capable of multi-occupancy (up to three agents). The spatial layout of lecture theatres includes desks, seats, aisles, a front area and a back area. Figure 1 presents an example of the spatial layout of a lecture theatre that has been used in the preliminary simulations. As shown in Figure 1, there are two exits represented by two abreast cells, two aisles, desks (coloured green) and seats (coloured yellow). Every cell of an exit is defined as an Exit Cell (EC) whereas every cell of an aisle is defined as an Aisle Cell (AC). Exits and aisles both can be defined by three parameters: quantity, width and location. In addition, the width of the front area and back area, number of rows and columns of desks and seats can be set by the user of the agent-based modelling and simulation system.

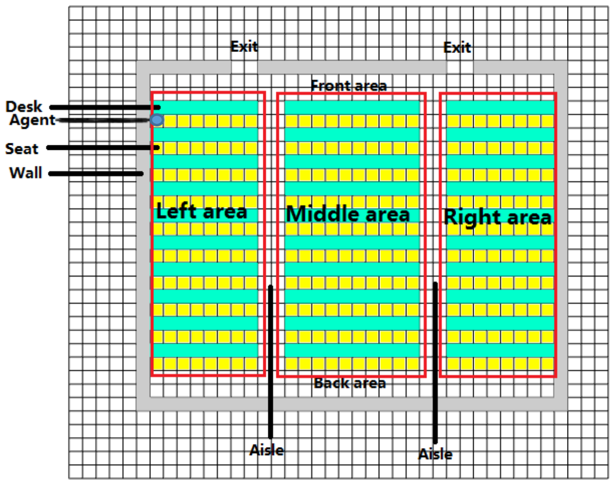
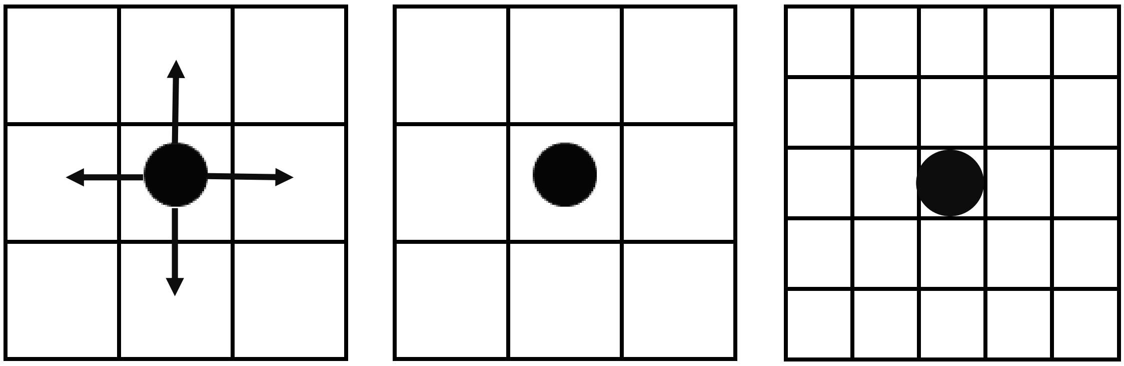


Figure 1. Example Layout of a Lecture Theatre

Agent Behaviour

Basic Movement

In the model, time and space are discrete and an agent can move one or two space steps (one space step means one cell) at every time step. Most studies on emergency evacuation in square lattices are based on either the von Neumann neighbourhood (VN) (Joo et al., 2013; Lu et al., 2016; Zheng and Cheng, 2011) or the Moore neighbourhood (MN) (Wang et al., 2015; Sun and Li, 2013; Heliövaara et al., 2013; Song et al., 2016). Figure 2(a) presents a VN where the agent located in the centre cell can move to its neighbouring 4 cells in a single time step. Figure 2(b) presents a MN where the agent located in the centre cell can move to its neighbouring 8 cells in a single time step. In real life dense crowds, the number of immediate neighbours is usually closer to 8 than to 4 (Heliövaara et al. 2013) and thus, the choice of the MN is viewed as a natural choice for the model presented in this paper when an agent moves one space step in a single time step. However, when an agent moves two space steps in a single time step, it can move beyond the neighbouring 8 cells of a MN. Therefore, the MN has been extended to 25 cells where the agent can move to its neighbouring 24 cells in a single time step as shown in Figure 2(c).



(a) Von Neumann Neighbourhood (b) Moore Neighbourhood (c) Extended Moore Neighbourhood

Figure 2. Agent Neighborhood

According to the layout of the lecture theatre and the initial location of agents in the seating area (coloured yellow in Figure 1), algorithmic steps of each agent's evacuation process are defined in three stages. Prior to defining these stages, it is noted that at every time step an agent calculates the distances between itself and different ECs in order to choose the nearest one. The chosen EC is called the Goal Exit Cell (GEC).

Stage 1: If an agent is located in the seating area, then

If it is in the left area (or right area) (see Figure 1), then move to the aisle to the right (or left).

Else if it is in the middle area (see in Figure 1): (1) the agent determines the closest AC; (2) if the closest AC and GEC are both on the left side (or right side) of the agent, then it will choose to move to the left (or right); (3) else the agent determines the AC closest to its GEC and there is a probability of moving to the closest AC or moving to the AC closest to its GEC. The chosen AC is called the GAC.

Stage 2: If the agent has left the seating area and is located in an aisle, then it moves along the aisle towards its GEC. The agent does not always move in a straight line due to the occupancy of surrounding cells. For example, if the cell in front of the agent is empty, then the agent will move into this cell. Otherwise, the agent will attempt to move to an AC which is empty.

Stage 3: If the agent has left an aisle, then it moves towards its GEC. At one space step, the Goal Cell (GC) of the agent will be selected from its MN. Here, the GC is used to refer to the cell that an agent chooses to move to at each time step. If the GC is closer to the GEC than the cell that the agent currently occupies, then it will move to the GC; else the agent will stay in the same location.

Individual Behaviour

Competitive behaviour, cooperative behaviour and conflict - In an evacuation situation, as time elapses people's stress level is likely to increase. Driven by high levels of mental stress, people will behave in a competitive manner (Pan 2006, Fang et al. 2016). In this model, a numerical stress level is used with the initial stress level of all agents being set (the same or different) before a simulation is carried out. At each time step, the stress level of an agent will increase by a defined quantity. A parameter *stress threshold* is used which is a boundary condition that measures the effects of stress (Pan 2006). When agents have a stress level that exceeds their stress threshold, they will no longer behave cooperatively, rather the agents will exhibit competitive behaviour.

Competitive behaviour is frequently observed in emergency evacuation situations when people compete for opportunities to evacuate more quickly. In this model, a competitive agent (competitor) executes the following behaviour rules.

(1) Move to its GC even if the cell is occupied by one agent or two agents.
(2) Move two space steps in one time step providing the movement rules allow; for instance, if the competitor's GC at some time step is already occupied by three agents, then it cannot move to its GC. The extended MN is used here as the movement range of the competitor is 24 cells.
(3) All agents with the same GC in a normal MN are called a group. In such a group, competitors are

allowed to move before co-operators. However, in a group with more than one competitor, conflicts between these agents can arise, thus preventing movement. The rules for representing a conflict will be discussed after cooperative behaviour.

Cooperative behaviour is likely to happen in emergency situations as recent work has proposed that people perform complex behaviours in emergency evacuation (Challenger et al. 2009, Aguirre et al. 2011, Fang et al. 2016) and they can evacuate in an ordered and cooperative manner not just competitive behaviour (Fang et al. 2016). In this model, a cooperative agent (co-operator) has the following behaviour rules.

(1) Move to its GC only if the cell is empty. If the GC is occupied by one or more agents, the co-operator will not move in this time step.
(2) Move one space step in one time step when the GC of the agent is empty. Otherwise, do not move in this time step. The MN is used here since the movement range of a co-operator is 8 cells.
(3) Within a group (as defined previously), co-operators will allow competitors to move first. If all agents in a group are cooperative, one of them is randomly chosen to move.
(4) When there are agents falling down in a co-operator's MN, the co-operator will carry out altruistic behaviour, i.e. the agent will temporarily ignore its GC and head to the falling agent in its MN.

Conflict between competitive agents can arise in evacuation situations. If there are M agents in a group and N of them are competitors then $\mathrm{M}-\mathrm{N}$ of them will be co-operators. At a particular time step, the co-operators in a group do not move whereas each of the competitors has the same probability of moving, Competitor Move Probability (CMP),

$$CMP = \begin{cases} 1, & CA = 0 \\ 1/(\mathrm{N} \times CA), & CA > 0 \end{cases} \qquad (1)$$

where CA is a measure of a competitors' Conflict Attitude ($0 \leq CA \leq 2$) (Bouzat and Kuperman, 2014). The stronger the CA of competitors in a group, the greater the value of CA and the lower the CMP. Equation (1) is adapted from Bouzat and Kuperman's equation (Bouzat and Kuperman, 2014), a form of which can be stated as,

$$CMP = \begin{cases} 1, & CA = 0 \\ 1/(N^2 \times CA), & CA > 0 \end{cases} \qquad (2)$$

Values of CMP obtained using equation (2) can be too low to reflect the probability of competitors moving in the scenarios considered in this paper. Thus, equation (1) is more appropriate for this model. When competitors do not conflict with each other, the value of CA is 0 and one of the competitors is randomly selected to move. The upper limit of CA is 2 because agents focus more on successful evacuation rather than engaging in conflict with no end. It is assumed that values of P of all competitors are the same. The Conflict Degree of a Group (CDG) is the product of N and CA and refers to the competitive degree of the whole group. Equation (1) demonstrates that at some time step, CMP decreases as N or CA increase. In real evacuation situations, many people compete for one place and the action of these people will lead to it being difficult for all of them to move at the same time. This is called the "Faster is Slower" effect which means that in some situations, if people push harder when trying to exit a room through a door, the evacuation time can increase (Helbing et al. 2000).

Climbing behaviour - In reality, a person who sits far away from the aisle may need a long time to walk through the seating area (coloured yellow in Figure 1) which is occupied by other people. If the person is located in the first two rows or the last two rows, he/she may climb over desks or seats in an attempt to reduce their evacuation time. For example, in Figure 1, the agent (denoted by the blue circle in Figure 1) can move directly towards the exit after climbing over the desk immediately in front of it. In this model, an agent has a likelihood to climb over desks and seats when the location of the agent meets two conditions. One condition is that the agent is located in the first two rows or the last two rows of seating in the lecture theatre since when the agent is situated in other rows it is not time-saving to climb over desks and seats. The other condition is that the agent is situated more than three cells from its GAC since if the agent is nearer to the GAC then it would be time-saving to walk rather than climb over obstacles.

Falling down behaviour - Heliövaara et al. point out that it would be a topic for future modelling to develop their model to enable agents to fall down (Heliövaara et al., 2013). In this model, it is assumed that when an agent competes with other agents or tries to climb over obstacles, there is a probability of falling down. If an agent falls down and does not receive help from other agents, it will remain in the same location for five time steps and then resume evacuating. However, during the period of remaining still, the agent that has fallen down can recover and then move immediately if an agent demonstrating altruistic behaviour arrives at its location in order to help.

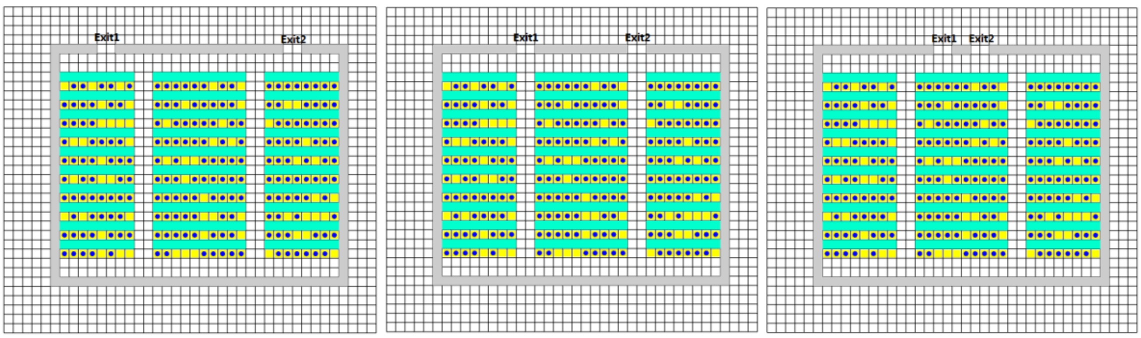
INITIAL SIMULATION RESULTS

Agent-based simulations have been carried to examine the effect on evacuation of (1) exit location and (2) competitive behaviour.

Effect of Exit Location on Evacuation

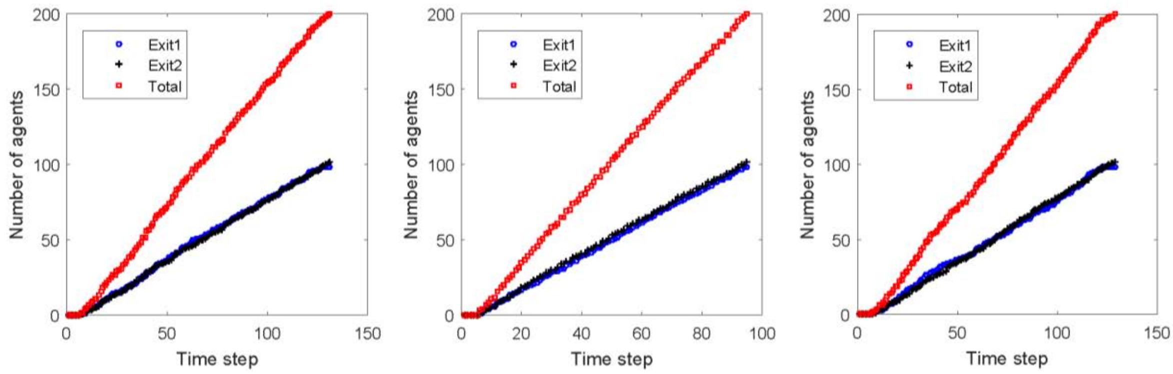
Three scenarios have been simulated each with different exit locations in the lecture theatre, S1-S3, as illustrated in Figure 3. In these simulations, agents behave according to basic movement as outlined in the previous section. Based on the actual layout of a lecture theatre with dimensions approximately 15m × 12m, the size of the lecture theatre modelled is 30 × 24 cells and the numbers of rows and columns of seating are 10 and 26 respectively. In each simulation, 200 agents are distributed in the lecture theatre with 57, 79 and 64 agents initially located in the left, middle and right seating areas respectively. While this initial distribution of agents is random, it has been kept the same in each simulation in order to ensure the results can be compared to each other. Furthermore, the simulation for each scenario has been repeated 10 times.

Figure 4 shows the relationship between the number of evacuated agents (total evacuated agents, evacuated agents via Exit 1 and evacuated agents via Exit 2) against time for each of the three scenarios simulated. From Figure 4, it can be seen all of the relationship curves are approximately linear, which can be attributed to the agents executing basic movements such that they evacuate in an ordered way and the moving velocity of the whole crowd is stable. Also, the relationship curves of agents evacuating through Exit 1 and Exit 2 are almost coincident, which can be explained by the near-uniform initial distribution of agents' locations and agents always choosing the nearest exit to egress. The mean evacuation time for each scenario is presented in Table 1 in which it can be seen that the evacuation time for S1 and S3 are approximately equal. It is noted that in S1 and S3, Exit 1 (the left exit) is distributed symmetrically about the left aisle. Similarly, Exit 2 (the right exit) is distributed symmetrically about the right aisle. It is suggested that the relative location between the exits and aisles in S1 and S3 is the reason why their mean evacuation times are approximately equal. In Table 1, it is also seen that the mean evacuation time of scenario S2 is approximately 30 time steps lower than that of S1 and S3. As intuitively expected, with the exit locations in alignment with the aisles in S2, once agents are in the aisles they are able to move directly to the exits without turning left or right thus improving evacuation efficiency.



(a) S1 (b) S2 (c) S3

Figure 3. Lecture Theatres with Different Exit Locations



(a) S1 (b) S2 (c) S3

Figure 4. Number of Evacuated Agents versus Time

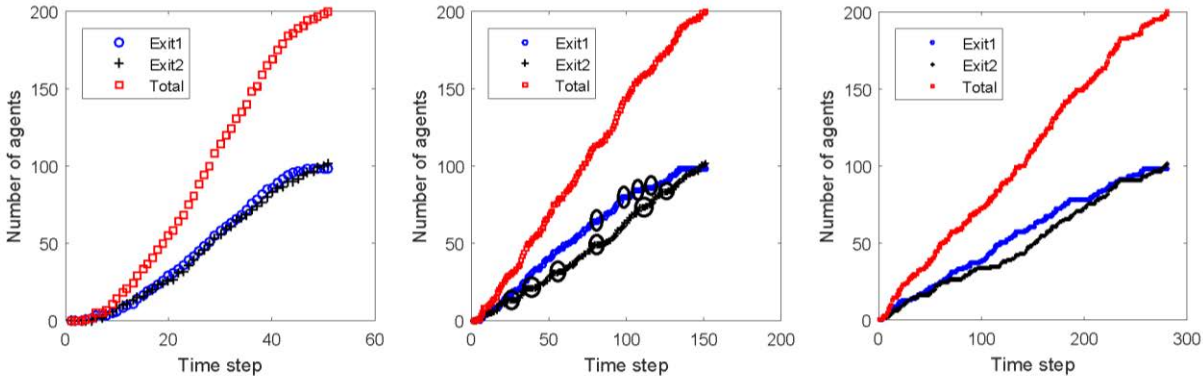
Table 1. Mean Evacuation Time

	S1	S2	S3
Evacuation time	129.1	97.4	129.4

Effect of Competitive Behaviour on Evacuation

In examining the effect on evacuation of competitive behaviour, the lecture theatre layout of scenario S2 has been selected (illustrated in Figure 3(b)) given this yielded a lower mean evacuation time than S1 and S3 in the simulations reported earlier. Furthermore, in examining competitive behaviour, three cases are considered. Case 1 (C1) involves no conflict between competitive agents (with CA = 0 in equation (1)). In Case 2 (C2) and Case 3 (C3), varying degrees of conflict exists between competitive agents. Specifically, in C2, CA = 1 (in equation (1)) whereas in C3, CA = 2 (in equation (1)). To reflect variation in individuals, the initial stress level of each agent ranges from 0 to 30 with the stress threshold set as 30. When an agent's stress level exceeds 30, the agent will stop behaving in a cooperative manner and begin behaving in a competitive manner. Simulations for these three cases have been repeated 10 times with the same initial distribution of agents as seen in those conducted when examining the effect of exit locations on evacuation.

Figure 5 presents the relationship between the number of evacuated agents (total evacuated agents, evacuated agents via Exit 1 and 2 respectively) against time for the three conditions simulated.



(a) C1 (b) C2 (c) C3

Figure 5. Number of Evacuated Agents versus Time

For C1, in which conflict does not exist between competitive agents, Figure 5(a) indicates that the total number of evacuated agents (shown in red) increases at a rate of approximately 0.6 agents per time step from 0 to 10 time steps, 2.3 agents per time step from 10 to 20 time steps, 2.9 agents per time step from 20 to 40 time steps, and 1.2 agents per time step from 40 to 50 time steps. The increase in evacuation rate beyond 20 time steps could be attributable to almost all 200 of the agents changing their behaviour from cooperative to competitive, due to their stress threshold being exceeded, by this time step in the simulation. Once an agent exhibits competitive behaviour, it is able to move two spaces steps in a single time step to reach its GC even if occupied by one or two other agents. Also in Figure 5(a), the evacuation rate of agents via Exit 1 (shown in blue) and Exit 2 (shown in black) is seen to be approximately the same.

For C2, in which a degree of conflict exists between competitive agents, it can be observed in Figure 5(b) that the total evacuation rate fluctuates throughout the simulation period. Furthermore, it can be seen that at certain points no agents evacuate the lecture theatre via Exits 1 and 2; four 'plateaus' (highlighted by black circles) for Exit 1 (shown in blue) and six plateaus (highlighted by black circles) for Exit 2 (shown in black). It is suggested that these periods on non-evacuation occur due to conflict between competitive agents. Also seen in Figure 5(b), evacuation via Exit 1 (shown in blue) is greater than that via Exit 2 (shown in black). This feature corresponds with the fact that conflict between competitive agents via Exit 2 is greater than that via Exit 1, shown by more 'plateaus' of non-evacuation in Exit1 than Exit 2.

For C3, in which a greater degree of conflict exists between competitive agents (than in C2), Figure 5(c) shows that the total evacuation rate fluctuates more frequently throughout the simulation period than that of C2 in Figure 5(b). Also, for C3, in considering evacuation via Exit 1 and Exit 2, it can be observed in Figure 5(c) that no agents evacuate the lecture theatre at more points during the simulation than in C2 (shown in Figure 5(b)); approximately ten and thirteen 'plateaus' (not highlighted) for Exit 1 (shown in blue) and Exit 2 (shown in black) respectively. This may be the reason why the total evacuation curve in Figure 5(c) shows more fluctuations than that of Figure 5(b). Furthermore, in Figure 5(c), evacuation via Exit 1 is greater than that via Exit 2 from approximately 100 to 200 time steps. This corresponds to the fact that evacuation via Exit 2 has more instances (approximately 3) when no agents evacuate the lecture theatre than via Exit 1.

Table 2 indicates the mean evacuation times for C1, C2 and C3, using the lecture theatre layout of scenario S2 with exit locations in alignment with the aisles.

Table 2. Mean Evacuation Time

	C1	**C2**	**C3**
Evacuation time	41.1	138.5	274.8

From Table 2, it can be seen that the evacuation time for C1 in which conflict does not exist between competitive agents is significantly less (a factor of 3.4) than that for C2 where competitive agents have a degree of conflict. In addition, the evacuation time for C2 is less (a factor of 2.0) than that for C3 where competitive agents conflict with each other to a greater degree.

CONCLUSION AND FUTURE WORK

The ongoing research reported in this paper is aimed at designing an agent-based modelling and simulation system to provide decision support for the layout design of lecture theatres and human behavioural management in emergency evacuation. Research to date has produced an initial system that enables (a) the design of the spatial layout of lecture theatres, and (b) evacuations to be simulated via an agent-based model incorporating behaviours in terms of basic movement and at an individual level. A preliminary investigation has been undertaken to examine the effect of exit location and competitive behaviour on evacuation time. Simulation results show that evacuation efficiency is improved when exits are in alignment with aisles. Furthermore, results show that competitive behaviour does not always increase the evacuation time depending on if the competitive agents conflict with each other. Although the simulation experiments may be intuitive, they provide a foundation for more complex scenarios to be considered. Future work will focus on further development of spatial layout design and agent behaviours. First, the spatial environment of the model will move from a single lecture theatre to a floor of a building with multiple rooms such as lecture theatres and small classrooms to a whole building with multiple floors. In addition, the model will take group behaviour and crowd behaviour into account to represent agent behaviour closer to reality. Also, future work will concentrate on customization that allows user definition of different spatial environments and agent behaviours. With all these efforts, the system can be used by emergency managers, designers and administrators who are charged with disaster mitigation in educational establishments to (1) evaluate the effects of different layouts on crowd evacuation dynamics and (2) better manage human evacuation behaviour.

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