A CROWD MOVEMENT AND BEHAVIOUR OBSERVATION TOOL WITH CONFIGURABLE INDIVIDUAL AGENTS TO SUPPORT BUILDING LAYOUT DESIGN AND NAVIGATION PLAN

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ABSTRACT

This paper presents a configurable simulation tool that can simulate crowd movement and behaviour in real time. The tool has three main features: (1) demonstrate the impact of altering building layout (e.g. size of gates, positions of corridors); (2) highlight the effects on crowd behaviour and movement by varying the crowd composition; (3) demonstrate the influence of different external factors (e.g. signs, guide people) on crowd behaviour. The simulation results can be used to help improve building layout design or optimise navigation plans. This tool takes the multi-agent system approach to build a crowd model. Each agent represents an intelligent individual in the crowd and has a unique set of parameters to distinguish it from others. Agent conducts its behaviour by combining basic steering behaviours. Steering behaviours contain steering forces that are calculated by considering surroundings (including crowd and environment objects) as well as individual parameters. All of parameters and steering behaviours are configurable in order to fine-tune the crowd and environment to fit various scenarios. Crowd are formed through interaction and collaboration between agents and environment. Crowd movement and behaviour can be observed from the real time simulator. By altering building structure layout, composition of crowd and navigation plans, crowd movement and behaviour will change accordingly. Such observations and results will provide useful feedbacks to designers and planners.

Keywords: Crowd Simulation, Crowd Modelling, Multi-Agent System, Decision Support.

1. INTRODUCTION

When designing certain types of buildings that require to accommodate large crowd, such as stadium and airport lounge, it is important to understand how building layout (e.g. numbers of exits, size of corridors and positions of gates) affects the crowd movement. For existing buildings, emergency incidents in crowded environment could cause crowd panic thus result in fatal casualties during evacuation. It will be beneficial to predict the crowd movement and behaviour in such situation. Usually, designers and planners rely on their experience and basic rules (e.g. building regulations). The reality is that, in different circumstances, various compositions of crowd will result in different crowd behaviours. It is very difficult and costly to carry out a drill to test a building layout for emergency navigation plan. Besides, it is also hard to distinguish differences between similar layouts and plans. A simulation tool that can observe the crowd movement and behaviour in real time will be very helpful to these scenarios.

Previous studies (Pelechano & Badler 2006; Shendarkar et al. 2008) usually focused on crowd model itself but did not pay much attention to the design of simulation tool. In this paper, we introduce a crowd simulation tool with an emphasis on crowd modelling as well as taking the flexibilities of configuration and future expansion into account.

This paper is organised as follows: section 2 is related works and literature review; section 3 presents design and implementation of the simulation tool; in section 4, six sets of simulation experiments are presented; conclusions and future works are described in section 5.

2. RELATED WORK

In the past 20 years, many models (Zheng et al. 2009) have been developed to present and display several typical crowd phenomena (e.g. clogging, pushing, unadventurous exiting and faster-is-slower). These models have taken different approaches. For example, Cellular Automata (CA) models (Kirchner & Schadschneider 2002) focused on the rules that decide how person moves to empty position. Social force models (Helbing & Molnar 1995; Helbing et al. 2000) considered that each person is affected by a force that is generated from nearby crowd or physical objects. Agent-based models (Macal & North 2007) were more concerned about how human make decisions.

Force-based models considered that individuals in the crowd were affected by some forms of forces. Motions of individuals were determined by total effects of forces. Forces are calculated by a set of formulas. This idea was first seen in the 'Boids' program (Reynolds 1987) which could simulate the motion of bird flock. In the flock, each bird updated its position by applying a steering force. Later, social force model (Helbing & Molnar 1995) was proposed to describe the movement of pedestrian. The pedestrian's movement was determined by the forces that are generated from his/her own desire plus repulsions/attractions from other pedestrians and objects. This model had been further developed (Helbing et al. 2000) to simulate panic situations by mixing social psychology. Panic evacuation from a room (Parisi & Dorso 2007) had been simulated by applying social force model.

Human intelligence was usually ignored in force-based models because the process of thinking and decision making is difficult to be represented only by mathematical equations. Agent-based models (aka. multi-agent system) contain autonomous agents which make their own decisions and can be used to simulate human systems (Bonabeau 2002; Macal & North 2007). The agent-based models were usually combined with CA models to represent the movement of agents (Bandini et al. 2007). As agents can be easily attributed, individual behaviours have been considered in many agent-based models (Pelechano & Badler 2006; Braun et al. 2003) and the results showed that individual behaviours could affect crowd behaviours to some extent.

It is possible to combine force-based model with agent-based model to integrate some level of human intelligence as well. For example, intelligent autonomous agents could be created through implementing steering behaviours (Reynolds 1999). Agents were used to simulate group behaviour with social force model (Braun et al. 2003). It had been suggested (Pelechano & Badler 2006) that agent-based model can be used at a high level for communication and wayfinding, while social force model can be applied at a low level to present the crowd local motions. However, challenge remains on how to integrate multiple human behaviours into a force-based crowd model and then implement the model into a simulation tool.

In this paper, we propose to create a crowd simulation tool that can enable real time observation with an emphasis on the crowd model. The crowd model is the further development of authors' previous work (Sun & Wu, 2011) which combines force-based model and agent-based model together through integrating forces into behaviour decision process and then converting behaviours into forces to affect the motions of agents. The design of the tool is considered not only to provide flexibility to configure both individuals and simulation environment but also the compatibility to expand in further studies.

3. TOOL DESIGN AND IMPLEMENTATION

The tool aims to achieve three goals: (1) demonstrate the impact of altering building layout (e.g. width of corridors and positions of doors) on crowd; (2) configure individuals in order to find out the effects of various crowd compositions on crowd behaviour and movement; (3) show how external factors (e.g. signs, guide people) affect crowd behaviour. In order to achieve the flexibility of configuration and the compatibility of future expansion, the tool consists of three modules: crowd model module, simulation world module and graphic engine module. Each module is designed as independent as possible and communicates with each other through interfaces. In this way, the impact of any changes made to one module could be minimized to other modules. For example, the crowd model module could become more complex in further studies while the graphic engine module can remain the same.

3.1 Crowd Model Module

The crowd model is the core module of the tool. It presents the information that is used to describe individuals as well as the mechanism of how to decide the movement and behaviour of every single individual in crowd. The crowd model is built based on the 'Boids' model (Reynolds 1987), the social force model (Helbing & Molnar 1995; Helbing et al. 2000) and the steering behaviours model (Reynolds 1999). In our model, the effects between entities (include individuals and other physical objects) are represented in forms of forces. These forces will determine the behaviours of individuals by taking into account the personal parameters. The resulted behaviour will also be converted into forces, which are represented in the model. The model also adopts the multi-agent system approach (Bonabeau 2002) to simulate the decision making process of an individual who is represented as an intelligent agent in the model (the term "agent" will be used from now on).

The crowd model can be viewed at two levels. In the lower level, the model can be seen as how an agent changes its position. Agent's movement is affected by the forces generated from itself, nearby crowd and surrounding objects. It will update its position when a steering force (an effect that changes agent's position) is applied. A fine network (2D coordinates) is utilized in this model to represent the continuous position of each agent.

In the higher level, the model describes how an agent reacts to others and how it decides and conducts its own behaviour. Multi-agent system approach is adopted to simulate the decision making process. The agent's behaviours are determined based on: behavioural rules, agent's current status, personal parameters and perception of simulation world. As a result, the final behaviour will be translated into final steering force.

The crowd model is consisted of three sub modules: (1) Behaviour Library; (2) Agent Information; (3) Action Engine.

3.1.1 Behaviour Library

Behaviour library consists of a set of pre-defined behaviours (rules), which determine how an agent will act under certain situations. Agent's status, personal parameters and its perception will decide which rule to apply and to what extent. Some basic behaviours (e.g. seek to, stop, avoid and walk away from) have been established in our model. Each of these basic behaviours will generate a steering force to agent. The force is in the form of 2D vector (For the purpose of computer animation, force is represented as an effect of changing agent's position on the screen in one time frame). Agent updates its position through applying the final steering force to current position.

Complex behaviours (e.g. following, grouping and finding exit route) can be achieved by combining basic behaviours with additional behaviour rules. Personal parameters can also be taken into account during the combination process. For example, 'following the leader' behaviour can be achieved through 'seek to' a position at the back of the leader; 'grouping' behaviour can be interpreted as the agent 'seek to' the average position of nearby crowd; 'finding exit route' requires a waypoint provided by the wayfinding service is used as the target in 'seek in' behaviour. In these behaviours, 'seek to' served as a common base behaviour. The agent status, personal parameters and perception can affect how to choose the 'seek to' position and the desired speed. These can be reflected in the additional rules.

A detailed example given here is the behaviour 'repulsive effect from nearby crowd'. This behaviour describes the agent will feel repulsion from other agents within certain distance. The repulsions from crowd can be calculated through the following equation:

$$\mathrm{RF_c} = \sum_{i=1(i\neq s)}^{n} \frac{\mathrm{K_c} \times (\mathrm{P_i} - \mathrm{P_s}).\mathit{Normalize} \times \mathrm{S_d} \times \mathrm{RM_i} \times \mathrm{RM_s}}{\mathrm{D_{is}}}, \quad (\mathrm{D_{is}} < \text{threshold})$$

In the equation, n represents total number of agents within the agent's sense range. K_c is a constant that can be used to adjust the scale of unit force (calculated through 'Normalize' operation). P_i and P_s represent the position of agent i and the agent itself. S_d is the desired speed of agent which usually equals to agent's default speed but could be changed on varies situations (e.g. the agent may want to slow down in a congestion and may speed up when find something interesting). RM_i is the modifier that indicates to what extent agent$_i$ can affect the agent$_s$'s feeling of the force while RM_s indicates how much agent can feel. The default values are 1 and should be adjusted to fit the agent's role (e.g. a person with undesirable smell will have a big *RM* value so that everyone feels a large repulsion from him/her). D_{is} is the distance between the two. Our experiment suggested that threshold should be no smaller than 1 (Note. The unit of distance in this formula must fit the display coordinates, i.e. the real measurement has to be scaled before using in the formula. In our implementation, 1 pixel on the screen represents 0.05m in the real world, which means if the distance between the two agents is 0.5m, 10 should be used as the D_{is} value). When D_{is} goes shorter than threshold, threshold is used instead of D_{is} to calculate repulsion.

3.1.2 Agent Information

Agent information module comprises agent's status and personal parameters. Agent status includes position, state (rest, wandering, seek to goal, follow target or avoid collision), orientation (current and next), speed (default, current and desired), current target point and goal. These values can be changed during simulation.

Personal parameters consists of size, default speed, sense range, leadership, willingness to follow, probability of being affected by POIs (point of interests), desired distance from others, distance to feel repulsion, distance to reach maximum repulsion, repulsion modifier (to self and to others) and desired distance to wall. These parameters are considered as natural attributes and have static values in simulation.

3.1.3 Action Engine

Action engine can be treated as the brain of an agent. It follows agent action process (Figure 1) to calculate a steering force that is used to update agent's position. It interacts with the behaviour library, agent information module and simulation world to retrieve relevant information. Information retrieved from simulation world is called agent's perception. Agent's status will also be updated during the process. Action engine will notify the outcome of agent's behaviour to simulation world. Objects in simulation world may be affected correspondently. At each time frame, agent will repeat the action process to decide its behaviour and update relevant information.

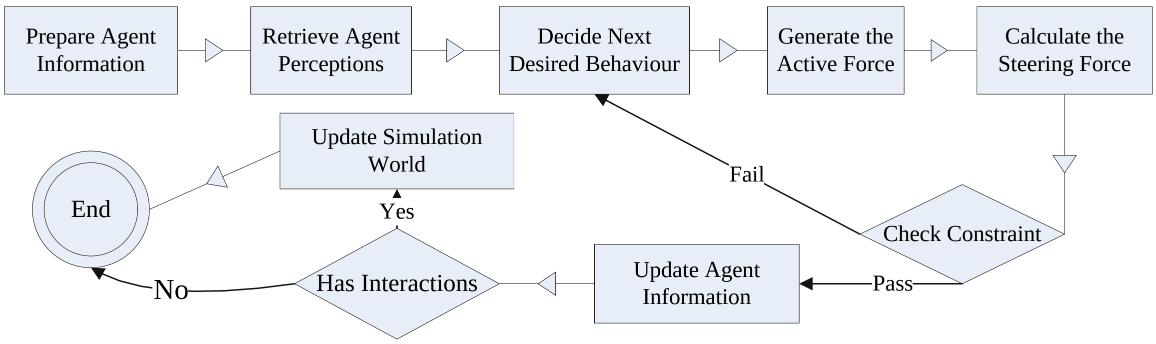

Figure 1: Agent action process.

3.2 Simulation World Module

Simulation world is the container of every single object and their relations. The objects include physical entities that can be seen from real time simulator (e.g. agents, obstacles and walls) and abstract objects (e.g. navigation map) that are not shown in the simulator. The simulation world has two functions: (1) provide relevant information to agents, who will use the simulation engine to update their status continuously; (2) provide the position and orientation of every object that will be represented in the simulator through the graphic engine.

3.2.1 Entities

Entities are physical objects (e.g. agents, walls, signs and obstacles) which can be interacted with the agents. Only agents will update their status continuously during the simulation. All the other entities will not be able to update their status actively. Their status can be updated through the interaction with agents.

Agents are the implementation of the crowd model described above. The other entities are much simpler in structure since they are currently designed as passive objects in the simulation. For example, walls contain following information: position, orientation, length, width, start position, end position and texture.

3.2.2 Navigation Map

Since all the entities have position and geometry information, they can be displayed graphically in the simulation tool. However, such information is not sufficient to simulate the navigation of an agent from one position to another. A technique called wayfinding is required here. In this tool, the Cell and Portal Graph (CPG) method (Pelechano et al. 2008) has been adopted. An example of a building layout and its correspondence CPG map is shown in Figure 2:

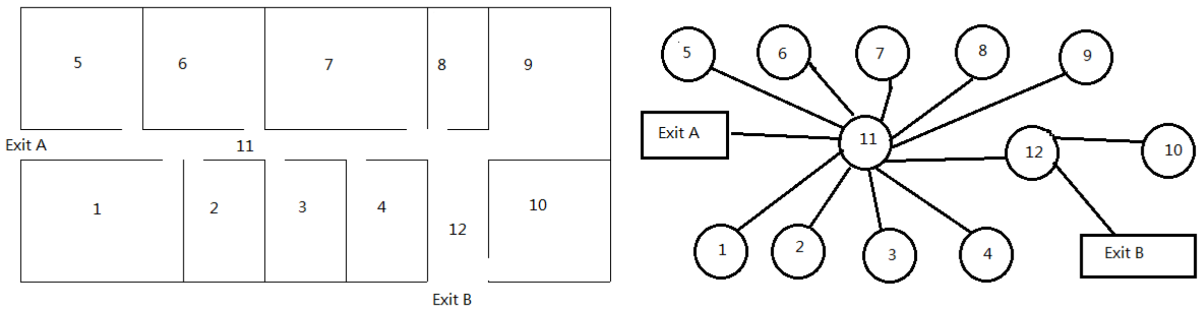

Figure 2: Layout of the building and starting position of the crowd.

Rooms, corridors and exits are converted into cells. Doors are translated into the links between cells. Agents move from one cell to another until reach the destination. Movement between any linked cells is straightforward and does not require any further navigation.

3.3 Graphic Engine Module

The function of graphic engine is to visualise the simulation world. It enables real time observation of the simulation process. The graphic engine is implemented through the Microsoft XNA framework. It only requires information of how to display the entities in the simulation world and is independent from the crowd model. Currently the simulator display crowd and simulation world in 2D as the aim of this tool is to observe the crowd movement and behaviour. If there is a requirement to represent the simulation in 3D in the future, the graphic engine can certainly be upgraded while the rest two modules can remain the same. For the purpose of computer animation, the graphic engine updates the display at 60 FPS (frames per seconds). In every updating circle, it first reads all the information that need to be represented from the simulation world module and then renders the objects in the simulator

4. TEST SIMULATION

A normal size (29m * 13.5m) building is selected to carry out the crowd simulation, which contains ten rooms and two exits (one as main entrance and others as emergency exit). In the test simulations, this building is assumed as a museum. Each room has 10 to 30 visitors at the time of simulation start. The test case is that all the visitors hear a fire alarm and then begin to evacuate. The room on the right bottom corner is not for public use so it will not be used in the simulation. The width of main entrance is 3 meters and the width of all doors of rooms is 1 meter. Default width of corridor is 1.5 meters. The emergency exit locates on the left (west) of the building and has the same width as corridors'. Six sets of simulations have been carried out to test configurable capabilities of the tool. Simulation set A is the baseline simulation with the default settings. The rest simulation sets have been configured into specific scenarios based on set A. In the simulation, the behaviour 'finding exit route' and 'repulsive effect from nearby crowd' are applied during the agent decision making process.

4.1 Simulation set A:

In this set of simulations, 140 people exit from the building. They only use the main entrance as the exit (It is assumed that they have no knowledge of the build so that use the entering route to exit). They are affected by the other people who are within 1 meter. The numbers (Table 1) and positions (Figure 3) of people in each room distribute as following:

Table 1: Distribution of people in each room.

Room1	Room2	Room3	Room4	Room5	Room6	Room7	Room8	Room9	Total
20	12	12	12	15	15	20	9	25	140

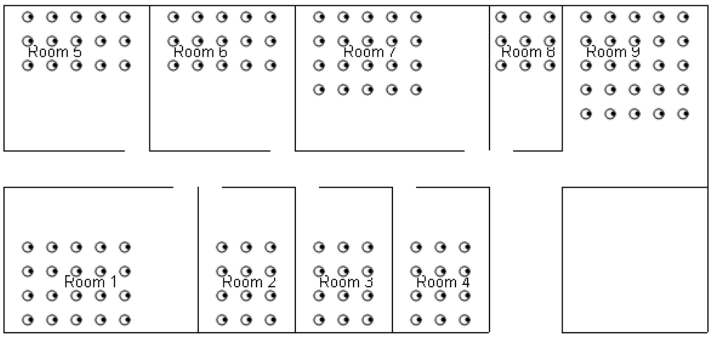

Figure 3: Layout of the building and the starting positions of the crowd.

The results in Figure 4 show how much time the crowd (by different speed) need to exit the building. It can be found that the slope of the line is quite large when speed is low (below 1.5 m/s) and the slope decreases as speed increases. At lower speed, the graph indicates that evacuation time increase dramatically when speed reduces. In the case of higher speed, the change of evacuation time is less significant comparing to the change at lower speed. For example, when speed decreases from 2 m/s to 1 m/s, evacuation time increases about 30 seconds; whereas speed decreases from 4 m/s to 3 m/s, evacuation time only increases about 5 seconds.

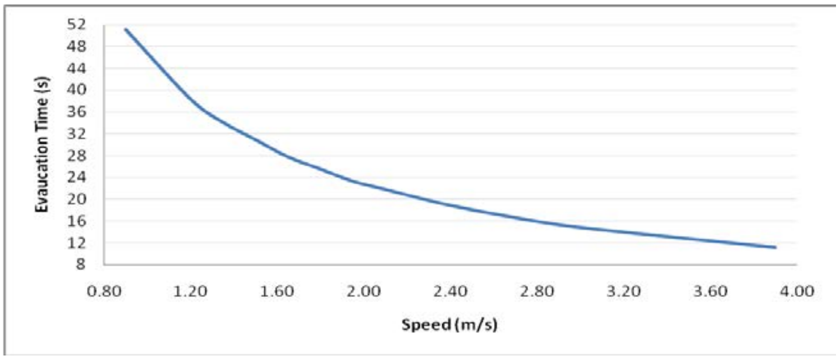

Figure 4: Evacuation time with various speeds (corridor = 1.5m)

4.2 Simulation set B:

This set of simulations aims to show the impact of changing the width of corridor. In this test, the width of corridor is increased to 2 meters (approximately three persons can walk in parallel in the corridor are observed in simulation) and 2.5 meters (approximately four persons walk in parallel). Figure 5 shows the results of evacuation time at different speeds for both cases. The curves are very similar although the widths of corridor are different. Comparing to the results from simulation set A, it can be found out (Table 3) that evacuation time can be improved with a wider corridor, but by increasing the width of corridor has an limited effect on improving evacuation time. This experiment indicates that the effect of the corridor's width on evacuation time is independent to the speed of crowd.

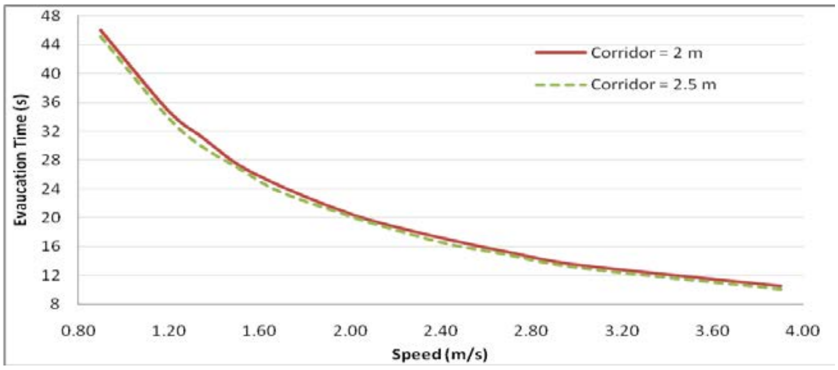

Figure 5: Evacuation time with various speeds (corridor = 2m, 2.5m)

Table 3: Comparison of evacuation time with different width of corridors (1.5m, 2m and 2.5m).

Speed (m/s)	0.90	1.20	1.35	1.50	1.65	1.80	1.95	2.10	2.40	2.70	3.00
2.0m : 1.5m	90%	91%	91%	89%	90%	90%	91%	90%	91%	92%	91%
2.5m : 1.5m	88%	88%	88%	88%	87%	88%	89%	88%	88%	89%	89%
2.5m : 2.0m	98%	97%	96%	99%	97%	97%	98%	98%	97%	98%	97%

4.3 Simulation Set C:

In this set of simulations, the crowd are consisted of a group (twenty) of elderly people and normal people. The elders move slower than the others do. The elderly group has been tested starting from both Room 7 and Room 1. The results are shown in Table 4:

Table 4: Evacuation time with different composition of crowd.

Speed (m/s)	Evacuation time (s)
All: 1.5	30.88
Room7: 1.2, Rest: 1.5	32.73
Room7: 0.9, Rest: 1.5	39.32
Room1: 1.2, Rest: 1.5	34.51
Room1: 0.9, Rest: 1.5	42.49

Comparing to the evacuation time (30.88 seconds) with all people move at 1.5 m/s, the evacuation time in the case of with a group of elderly people does have an increase. By comparing the two different starting positions (Room7 and Room 1), it is surprise to see that there are no much differences in the two evacuation times (3.17 seconds in the case of elderly people with speed 1.2 m/s; 1.78 seconds in the case of 0.9 m/s). Considering if elderly people start from Room 1, they have to move through the corridor to reach the door of Room 7, which should take them more than 10 seconds (The length of the corridor is 12 meters and the speed of the elderly people is 0.9 m/s or 1.2 m/s). The cause of this situation can be found from the real time simulator. In the case of elderly people starting from Room 7, they will slow down the behind crowd when entering the corridor, as they are hard to be overtaken. A gap also has been observed from the screen shot (the left part of Figure 6). That is because people in Room 8 and Room 9 move faster than elderly people do. Another phenomenon has been identified through the simulations as well. That is, when all the people have the same speed, the ones will evacuate quicker if they are in a room that is more close to the exit. If some people have slower speeds compare to the others, they will have difficulties to insert themselves into the crowd flow thus may have a longer evacuation time than those in the further rooms. The left part of Figure 6 is the simulation with elderly people in Room 7. It can be observed when all the rest rooms are empty, there are still half of the elderly people are waiting to enter the corridor. The right part of Figure 6 is the simulation of all people with the same speed. It can be seen that people leave the rooms at a similar rate.

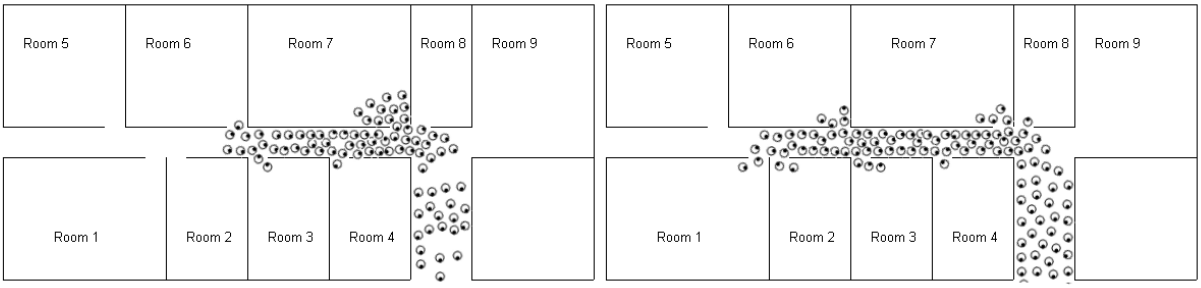

Figure 6: people speed: 0.9 m/s in room 7 (Left) and 1.5 m/s for the rest VS 1.5 m/s for all (right).

4.4 Simulation Set D:

In this set of simulations, the positions of the doors of Room 2 and Room 7 have been changed. By moving the doors of Room 2,3,6 and 7 closer, congestion (circled in Figure 7) has been observed near the four nearby doors.

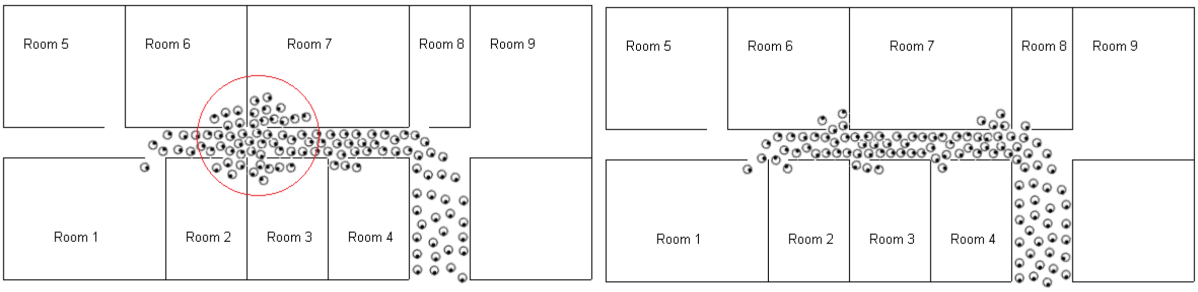

Figure 7: Congestion caused when doors are designed close.

Figure 8 shows positions of doors do have an impact on evacuation time. It costs about 10% more time to exit the building with the alternative door positions. It indicates that doors connect rooms to corridor should be distributed separately from each other in order to avoid congestion. If several rooms have their doors close to each other, this could cause congestion because people need to enter the same area of corridor.

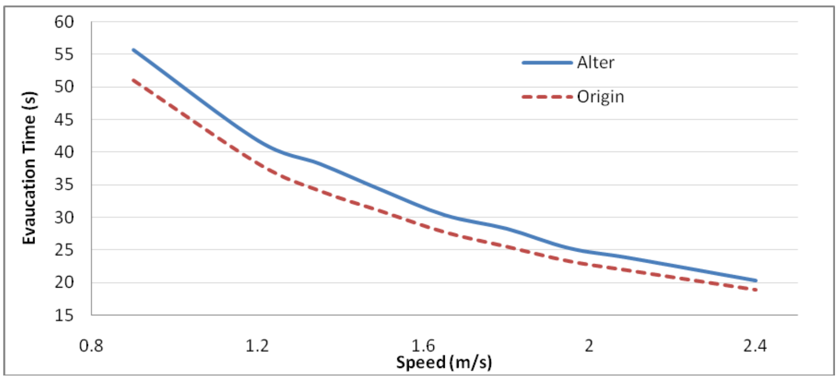

Figure 8: Evacuation times with original layout and alternative layout.

4.5 Simulation Set E:

This set of simulations adds some elderly people (speed = 0.9m/s) in corridor near the door of Room 1. Their starting positions are shown in Figure 9.

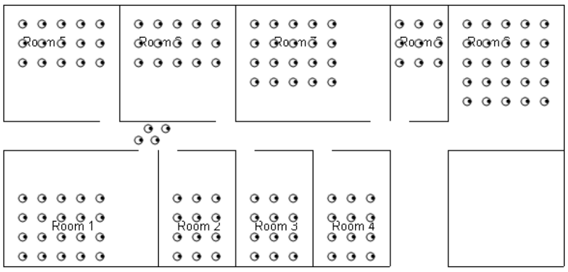

Figure 9: Positions of elderly people (case of 4) in corridor.

Results (Table 5) reveal slow moving people could have an impact on the total evacuation time. As the amount of such people increasing, the longer evacuation time is required.

Table 5: Results of evacuation time with elderly people (speed=0.9m/s) in corridor.

Number of Elderly	0	1	2	3	4
Evacuation time (s)	30.88	31.65	33.20	32.13	35.33

4.6 Simulation Set F:

This set of simulation shows the evacuation of people with the ability to make use of the emergency exit. It is assumed that people in Room 1,2,5 and 6 are informed (can be achieved by providing a guide or a sign) to use the emergency exit. Figure 10 shows using a proper exit route can decrease evacuation time significantly. The evacuation times are around 33% less when comparing to use only one exit at various speeds, which is much more efficiency than increasing the crowd speed or the width of corridor. It indicates that a good emergency plan (navigate crowd to use proper exit route) is crucial in an emergency evacuation.

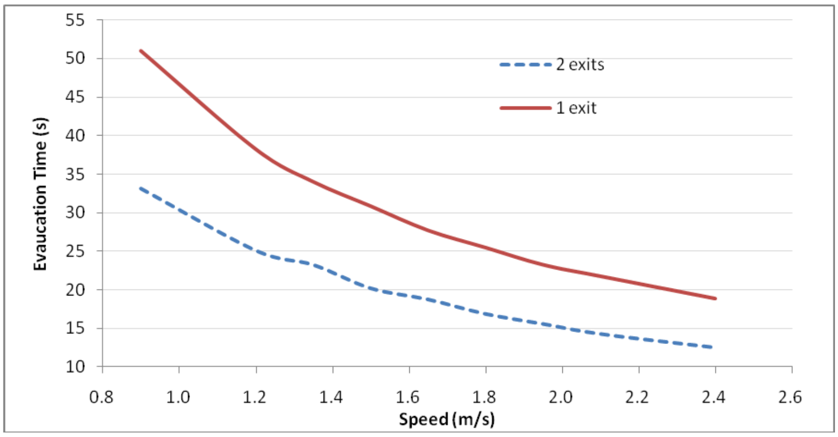

Figure 10: Evacuation time with using differets exits.

5. DISCUSSION AND FUTURE WORK

In this paper, we have present a crowd simulation tool based on a crowd model that integrates multiple human behaviours through personal parameters. Experiments have been carried out with various configurations. The observation results suggested that the tool is able to demonstrate the impacts of modifying building layout, changing crowd composition or altering navigation plan.

Further research is required to improve the three modules in the tool. Firstly, the crowd model calibration is currently based on authors' experience and common knowledge. It needs to be validated with real cases data and human behaviour knowledge from psychological research should be considered to fine tune the model with correct settings of configuration. Future work also includes expand the behaviour library and increase intelligence of the agent to achieve a more realistic simulation. Secondly, the simulation world only contains simple static objects at this stage. Dynamic objects and special effects (e.g. fire or smoke) could be brought into simulation in the future studies. Finally, the graphic engine can be improved to provide a better visual experience.

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