An Agent-based Simulation Model for Emergency Egress

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Abstract. Unfortunately, news regarding tragedies involving crowd evacuations are becoming more and more common. Understanding disasters and crowd emergency evacuation behaviour is essential to define effective evacuation protocols. This paper proposes an agent-based model of egress behaviour consisting of three complementary models: (i) model of people moving in a building in normal circumstances, (ii) policies of egress evacuation, and (iii) social models for integrating models (e.g. affiliation) that explain the social behaviour and help in mass evacuations. The proposed egress model has been evaluated in a university building and the results show how these models can help to better understand egress behaviour and apply this knowledge for improving the design and execution evacuation plans.

Keywords: Agent-Based Social Simulation, Evacuation protocol, Emergency Egress, Affiliation model

1 Introduction

Unfortunately, tragedies involving crowd evacuation appear frequently in the news, including natural and man-made disasters, such as massive parties, terrorist attacks and sports events. In these cases, many people become injured by the chaos produced because they did not know how to manage these situations. Thus, it is important to progress on the study of these situations learning from the past experiences and improving emergency plan strategies.

Emergency evacuation, known as egress, is a critical component of emergency response and requires developing in advance evacuation preparation activities ensuring people can get to safety in case of emergency. In order to define effective evacuation protocols, understanding disasters and crowd emergency evacuation behaviour is essential [1].

There are many research theories about mass psychology with the objective of understanding crowd behaviours in emergencies from several points of view: decision making, exit times, clinical issues and crowd behaviour [1]. For example, one of the most influential is exit selection and the time it takes to evacuate. Aspects, such as their familiarity with exits or their visibility are very important to choose the exit way. People personality has become another relevant aspect because it also influences to follow or cooperate with other users when they have to select the exit [6].

From another point of view, there are a lot of models and theories. Some previously mentioned studies [1,6] have analysed clinical issues, such as freezing or becoming disassociated from reality, which are also potentially dangerous. However, those researchers found other interesting findings; around 50 percent of emergency survivors referred unambiguously to a sense of unity or togetherness with the rest of the crowd during the emergency. Also, there is one model which explains why family groups often escape or die together, this is the affiliation model [1].

A full-scale evacuation demonstration is not viable because of ethical, practical and financial issues [8]. Therefore, models and simulations of crowd behaviour are widely used to analyse the effectiveness of evacuation preparation activities. Different computer-based simulation approaches are used in the literature for evacuation, such as flow dynamics [7] or cellular automate [5]. However, agent-based simulation (ABS) has been used as the preferred method to simulate crowd behaviour [14], because agents are particularly suitable for modelling human behaviour.

This paper proposes the use of agent-based social simulation for modelling an egress evacuation through three complementary models: (i) model of people moving in a building in normal circumstances, (ii) policies of egress evacuation, and (iii) social models for integrating models (e.g. affiliation) that explain the social behaviour and help in mass evacuations. The proposed egress model has been evaluated in a university building.

The remainder of this paper is structured as follows. In Sect. 2 the different simulation models analysed are presented. Whereas Sect. 3 shows the scenario used in the experimentation, the evaluation methodology and the results. Finally, a general discussion of findings and future research is presented in Sect. 4.

2 Simulation Model

The design of the simulation model is based on three complementary models. Firstly, we model the behaviour and daily routines of the occupants. Second, we model the behaviour and actions of the occupants in response to the threat and during the evacuation. This model is organised in two models, a model of the different policies for leaving the building and a model of the different social behaviours relevant for emergencies such as the affiliation model [4] or mobility disabilities [2]. The different models that are studied are implemented in the simulation by defining some parameters, such as new states and positions or different movement speeds.

Crowd Modelling in buildings The behaviour and activity of the occupants in the building are represented through occupancy agents, which can be defined using real patterns and characteristics. Agents have been modelled using probabilistic state machines. The states are the main engine to model the actions of people in the building. The occupancy agents performance in the building is controlled by the simultaneous action of schedules and Markov chains, in contrast with conventional static schedules.

Emergency policy Models When an emergency situation occurs, the occupants who are performing normal daily actions have to face it. According to [13], during the impact period, from 10-25% of the people remain united and calm, 75% manifest disorderly behaviour, bewilderment and 10-25% show confusion and panic. So we have modelled the agents in the worst case, they take sometime to react. When they notice that the emergency happens they try to go out. For this goal we have implemented three ways or policies for leaving the building.

1. *Nearest gate*. By means of this policy, the occupants leaving the building use the nearest gate when the emergency occurs. This technique could be the fastest way to evacuate the building, but it is not the safest considering that the fire could be in the way to this exit. If the fire progresses quickly and it is near from one of the exits, this fact could be dangerous if the agent tries to evacuate in that direction.
2. *Safest gate*. In this case, the occupants leave the building by the furthest exit in relation to the initial position of the fire. The path to this safest exit could be dangerous if this path contains any fire position.
3. *Less crowded gate*. The occupants, either quickly evaluating the decisions of the rest of the occupants or using information provided by a system of the building, knows an approximate value of the agglomeration at the exits and decides to go to the less crowded gate.

Social Models in emergencies On the other hand, two social behaviours are highlighted. Firstly, affiliation model has been chosen according to [14] because it is one of the most important crowd behaviour together with different kinds of reactions when an emergency happens. Other works [14] have observed that when there is an evacuation, families try to exit together by the same exit, meet at a point or someone take care of the youngest member and the rest leave the building. So in this project, the last behaviour is modelled. When occupants are defined they could belong to a family, each family have one child and one parent. Not every agent belongs to a family only a 20% have been modelled in this way to analyse the different results between agents with family and individual agents. When the emergency happens, each member of a family try to leave the building using the same way as his family whereas the child of each family stay stopped in his position waiting to his parent. This parent mentioned previously look for the child and go to the child's position. When they are together they try to leave the building in the same way as their family did. On the other hand, individual agents leave the building in their own way. An example of the different Markov states, the decisions and the probabilities assigned to them can be seen in fig. 1.

Secondly, modelling people with mobility disabilities, such as old people, is considered. These disabilities allow us to treat this kind of agents in a different

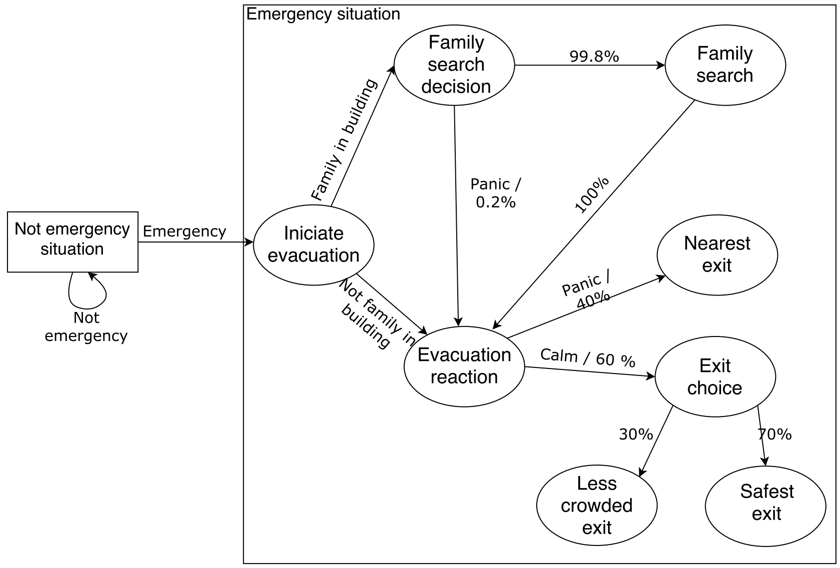

Fig. 1: Example of an emergency behaviour of the occupation

way because their velocity is slower than normal agents and they could take more time to react when there is an emergency.

3 Experimentation

3.1 Implementation and scenario

Recently a large number of Agent Based Social Simulation (ABSS) platforms have been made available, as recently surveyed in [11]. The most popular ones, MASON, NetLogo [12] and Repast [3] are developed in Java and provide general facilities for developing agent systems and its visualisation. In a previous work regarding evacuation, we selected UbikSim [10], which extends MASON and adds facilities for indoor visualization as well as an agent behaviour based on probabilistic state machines. Given the popularity of the Python ecosystem and its growing use for machine learning, we have opted for Mesa [9] in this work, which is developed in Python, includes a browser-based visualization module and allows using IPython notebooks for running the simulations and analyzing the simulation data. Since Mesa does not provide specific facilities for indoor modeling and visualization, we have extended Mesa as explained in this paper.

The system has been evaluated in a real-life scenario, the ground floor of Building B of the School of Telecommunication Engineers (ETSIT) of the Universidad Politécnica de Madrid (UPM). This floor has a rectangular shape and an area of 1600 m^2. The building is formed by four types of room: offices, laboratories, classes and transition spaces, such as halls, corridors or resting areas. The floor is divided into 41 rooms distributed as 14 offices, 20 laboratories and

4 classes and 1 hall and 2 corridors. There are two available exits, one to exit from building and another to enter to other connected building.

In order to model crowd and people in a normal situation at the university, firstly some data was collected. The collection was performed by a survey answered by 25 people, which had the aim to find the main habits of the people at the university. Some questions were about work time entry, stops for lunch and time in each dependency (classes, labs. . .).

3.2 Evaluation

The aim is to find the best policy of evacuation in each situation and type of occupant. This project is focus on:

1. *Exit time*: This time covers from the beginning of the emergency situation until the occupant has left the building, if he has succeeded.
2. *Number of dead agents*: This metric inform us about the number of agents that have died during the simulated evacuation.

Furthermore, five research questions are suggested, which are answered with averaged data obtained by successive simulations, executed with 50 agents. The questions raised are presented below together with the experimentation results.

RQ1: Does emergency time affect the evacuation? To answer this question, the simulation is made in three different hours. The obtained results are: at 10:20, 22 agents were in the building and 1 dead; at 12:00, 41 agents in the building and 2 dead, and at 3:00 p.m., 10 agents in the building and none dead. Depending on the hour there will be more or less agents in the building.

RQ2: What policy is more effective saving people? In this case, three simulations are made because there are three different policies: familiar exit, nearest exit and safest exit. The following chart shows the number of agents alive and dead in each situation. The total number differs due to the probabilistic model based on stochastic Markov chains. As can be seen in fig. 2, it can be concluded that the best policy to save people is 'Nearest exit'.

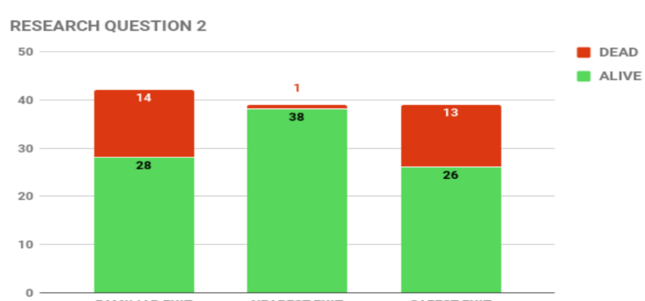

Fig. 2: RQ2 results

RQ3: Which policy gets the best evacuation time? In this case study, an evaluation of which policy leads to the best evacuation time is made. With this aim, the simulation features are the same than in RQ2. The obtained results, which are measured as the average time of evacuation in seconds, are 40,14 seconds using the *Familiar exit* policy; 42,77 seconds using the *Safest exit* and 27,65 seconds using the *Closest exit*.

Firstly, the best policy to get the best exit time is the 'Nearest exit' policy. On the other hand, the other policies have a similar exit time considering that can be the same exit in many cases.

RQ4: How do mobility problems impact on the evacuation? The simulations are made in this study including agents representing elderly people (50%), which walk slower than the general ones. A comparison between young agents and elderly agents using the nearest exit policy is presented in figs. 3 and 4.

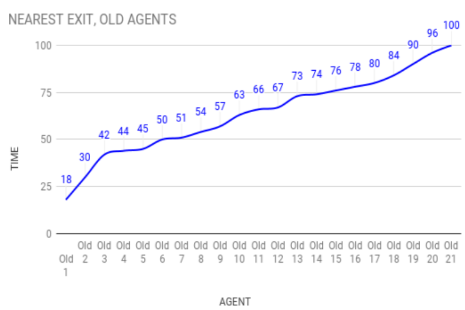

Fig. 3: RQ4 results: elderly agents

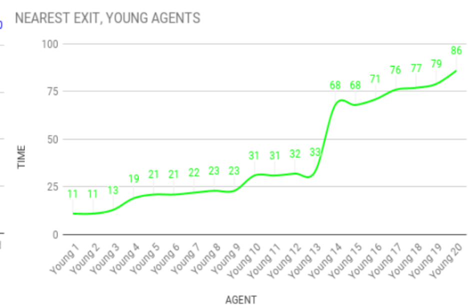

Fig. 4: RQ4 results: young agents

As it is obvious, elderly agents need more time to leave the building. However, some young agents are delayed by the elderly agents due to help them and follow them to the exit. This fact made young people more vulnerable to be dead as we can see in the chart in Fig. 5. In this chart can be also seen that elderly agents have more have more probability of dying. Specifically, the average time to leave the building is 63,71 sec (elderly agents) and 40,80 sec (general agents).

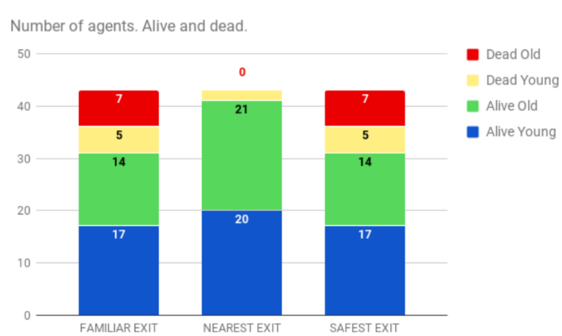

Fig. 5: RQ4 results: Number of dead and alive agents by type

RQ5: How do family ties affect in the evacuation? In this case, two families, which are formed by one child, one parent and another three agents, are included in the simulation. The results are evaluated comparing familiar exit and nearest exit policies. The data corresponding to both cases is presented in table 1.

	Exit time (seconds)			
	Familiar Exit		Nearest Exit	
Member	Family 1	Family 2	Family 1	Family 2
Parent	41	75	43	Dead
Child	44	74	45	Dead
Member 3	Dead	77	41	30
Member 4	46	Dead	43	36
Member 5	51	Dead	52	Dead

Table 1: RQ5 results

With the information of both cases, it can be affirmed that family ties affect the evacuation time, and also increase the probability of death. This fact is due to when the parent goes to look for the child they delay the exit time and the threat could be increased.

4 Conclusions and Future work

In this study, an evacuation simulator has been developed in order to study effective evacuation protocols. The aim is to analyse the best policy to leave the building defining and modelling agents with different features. Specifically, two social behaviours are used: affiliation model based on family relationships and modelling of people with mobility disabilities. In addition, three different strategies or policies to abandon the building have been studied.

First, Nearest gate, the occupants leave the building using the nearest gate when the emergency occurs. Second, Safest gate, the occupants leave the building by the farthest exit in relation to the initial position of the fire. Finally, less crowded gate, the occupants, either quickly evaluating the decisions of the rest of the occupants or using information provided by a system of the building about the less crowded gate.

In this paper, five research questions are suggested, which provide five main conclusions. First, the number of dead agents depends on the time the emergency occurs, being the worse scenario in hours of a greater concurrence of people in the building. Second, the best policy or strategy to leave the building is the 'Nearest exit' policy. Third, elderly occupants need more time to leave the building, and also some young occupants are delayed by the elderly agents. Finally, family ties affect in the evacuation time, and also increase the probability of dead.

The models considered, the policies proposed, and the results obtained are a useful aid to define new evacuation strategies and highlight the most relevant aspects that should be considered during their planning, determining the effective ways of setting appropriate evacuation policies.

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