Agent-Based Approach For Modeling Evacuee Uncertainty Behavior Using Game Theory Model

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Abstract: Reducing building evacuation time is a challenging research, which has been studied from any aspects up to now. In many of these researches to evaluate the proposed method a simulation has been used. Simulating building evacuation is cost effective and very accessible to all. However, the reality of the results of the simulation environment is very important. Each agent in simulation must exactly do the same as a panic evacuee performs in the disaster time. Uncertainty is attached to human behavior and especially in panic time it shows increase. However, the parameter of uncertainty has not yet included in evacuee behavior for evacuation simulation. In this paper, using game theory, an agent-based model has been proposed where the value of uncertainty during the time will be decreased. The results of this study showed that the evacuation time by considering uncertainty is not the same without considering it. Based on different scenarios it can be more or less. Nevertheless, this shows that without considering uncertainty, the results of evacuation simulation may not be close to real.

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1. Introduction

Building evacuation procedure has been studied for decades in many aspects until now, from architecture perspective to social engineering and computer modeling and simulations. As time goes the more complicated architecture of buildings make the process of emergency evacuation even more complicated. In current situation understanding the evacuee's behavior during the panic time can help to determine better solution for faster and safer evacuation process. This issue is such important that after passing years from 9/11 terrorist attack, still researchers exploring the evacuees' behaviors and actions during disaster (Sherman, Peyrot, Magda, & Gershon, 2011).

Computer simulations are great tools to practice evacuation without needs to do it on field. A simulation can estimate the evacuation time based on different types of inhabitants inside the building while adding the building statics to the simulation parameters. Researchers have introduced various kinds of evacuation simulations up to now. BuildingEXUDOS (Chunmiao, Chang, Gang, & Peihong, 2012), EGRESS, EXIT89, EXODUS, SIMULEX and ZET (Dressler et al., 2010) are some of the some instances of them (Gwynne, Galea, Owen, Lawrence, & Filippidis, 1999; Zhi, Lo, & Fang, 2003). The performance of an evacuation simulation is directly related to closeness of implementing panic behavior of evacuees inside it. Otherwise, the result of the simulation may report a fast evacuation, while in disaster time panic evacuees fail to leave the building on time.

In this paper an agent-based evacuee's panic behavior model based on game theory is proposed. The simulation model is agent-based where each agent (evacuee) has its own programming thread and, same as the real world, its decision is based on the external events and internal inference algorithm (Crooks & Heppenstall, 2012). Game theory has demonstrated a huge potential in predicting the outcome of the events which has many players inside where each player may have different strategies during play such as economy, war, sport plays and so on (Tadelis, 2012). This paper introduces a basic game theory model for agent decision-making process. Although this agent does not contain all the behaviors of a panic evacuee, it opens a framework for developing such agent.

2. Research Background

There are several different models for evacuation simulation experienced by researchers. Cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theoretic models, and approaches based on experiments with animals are the most cited ones in literatures (Zheng, Zhong, & Liu, 2009). Agent-based models are usually more computationally expensive comparing to other methods. However, implementing each evacuee as an agent creates the opportunity of having heterogeneous agents with different panic behaviors (Zheng et al., 2009). Such extensive behavior may not be easy implementable by other models. An agent-based model for evacuation has been proposed by (He & Zhao, 2010), where the behavior of evacuees on congestion near exit doors has been modeled. In this research we used agent-based models to model the evacuee's panic behavior.

It seems that creating evacuation simulation based on evacuee profile has been started by (Uehara & Tomomatsu, 2003). In this work there are three types of evacuees: self-reliant, incapacitate evacuee and attendant. In disaster time, self-reliant are escaping without any help or helping others. Incapacitate evacuees are not able to go by themselves and thus attendants help them in evacuation process. Different walking speed based on the evacuee type and density of people around have also considered in this work. The route selection of evacuees in this work is based on shortest path, which may not be feasible in the real scenarios. The social and familiarity factors of evacuees has also been noticed by (Shen, 2005), where mostly the effect of proposed model is on the walking speed and the route selection is still based on shortest path to exit. On the way to exit, evacuees, who are in panic mode, may push each other and this will reduce the evacuation process. (Wang, Luh, Chang, & Marsh, 2009) modeled both social bond and interpersonal bond of evacuees and studied its effect on evacuation time. To add more constraints to simulating the evacuation process, (Yuan & Tan, 2011) proposed a simulation model, where because of the fire smoke, inhabitance of the building cannot have low visibility and thus they need to search for the exit. One of the most recent and complete evacuee modeling is (Zhang, Li, & Hadjisophocleous, 2013). In this research, many parameters such as the smoke level, density of occupant, probability of using exit and the temperature of the compartment have been considered.

The problem of evacuation simulation is not always simulating the evacuee behavior. In some cases we need to determine the best possible evacuation time. This could create a benchmark line to current evacuation plans to determine their efficiency. (Li, Fang, Li, & Zong, 2010) proposed a route selection method based on genetic algorithm to find out the best possible paths for individuals for achieving to three objectives: minimizing the whole clearance time, minimizing the total travelling distance and minimizing the congestion. In this work, evacuees are homogenous and constant walking speed, which decreases on the congestion areas.

Although many works have been done to simulate the evacuee behavior, there are few works considering the dilemma of evacuee when he changes his decision and move backward for another way out. This could be happen because of lack of information from the disaster inside the building. Consider that evacuees try the first exit but then they face highly smoke area in the same area of lower floor. So, they need to go upstairs and try another exit to survive. Another reason of changing mind is when evacuee faces the congestion in the area and perhaps he can find another way out to evacuate the building faster. Such idea of changing evacuee route based on the online information has not yet implemented.

3. Game Theory

Game theory is defined as the study of compete or cooperation between agents based on a mathematical model (Myerson, 1991). Game theory model is categorized in several methods. A game theory is either zero-sum or non-zero-sum. In zero-sum, the wining of an agent inside the game means that others lost. However, in non-zero-sum, all players may have benefits of wining on the game. Evacuation modeling is a non-zero-sum game. A game theory can be sequential or simultaneous. In sequential agents play one after another while in simultaneous they are playing at the same time. In simultaneous game model, players are not aware of the latest decision of others. Building evacuation is a simultaneous game theory model.

Game theory has been practiced in building evacuation simulation. (Lo, Huang, Wang, & Yuen, 2006) developed a model based on game theory to see how agents choose the exit door in order to reduce the congestion and increase the evacuation speed, when several exits are available to evacuees. Although this work is based on exit selection, once an evacuee selects an exit, there will be no change to that. (Zheng & Cheng, 2011) also used game theory to simulate the relationship between evacuees during the panic time. In this game, evacuees choose to compete or cooperate in order to minimize the evacuation time.

4. Agent Model

An agent in this game is an evacuee and the goal for each agent is to reach to exit doors as fast as possible. The main goal of the game is to reduce the evacuation time. Let a_i represents an agent inside the game, t_i be the time needed for a_i to get to an exit door, then T is the evacuation time where $T = max(t_i)$. It means that the evacuation time is the time that the last evacuee (agent) gets to an exit door. This last agent (a_i) can be the last one in queue close to the exit door. Although a_i has already selected the exit door, at the time it realizes that it will take too long to pass the door, it may change his mind to go back and try another exit door.

For agent a_i, following information is available: location (X^{a_i}, Y^{a_i}) and direction θ^{a_i}. All the agents have similar speed and in congested environment and close to the doors the speed will be decreased. Table 1 shows the walking speed of agents during evacuation time. The walking speed of the agent a_i is shown as W^{a_i}. There is another walking speed parameter for agent a_i named as $W_k^{a_i}$, where k is the direction and $W_k'^{a_i}$ is the predicted average speed in that specific direction.

Table 1. Walking speed for agents based on the congestion and closeness to a door

Density	Close to door	Far from door
Less than 2 people/m^2	1.00 m/sec	2.00 m/sec
2-3 people/m^2	0.75 m/sec	1.50 m/sec
4-5 people/m^2	0.50 m/sec	1.00 m/sec
More than 5 people/m^2	0.38 m/sec	0.75 m/sec

The payoff function for the agent a_i will be derived as follow, where E_m is one of the possible exit doors, A is the area represented by a polygon, which contains obstacles, walls and doors. Eq. 1 shows the distance that agent a_i can travel in the time step t and Eq. 2 and 3 demonstrate how to calculate possible locations for agent a_i movement.

$$D^{a_i} = W^{a_i} * t \qquad (1)$$

$$\forall\, \theta_k \in \{1..360\}, X_k^{a_i} = X^{a_i} + D^{a_i} * \sin(\theta_k) \qquad (2)$$

$$\forall\, \theta_k \in \{1..360\}, Y_k^{a_i} = Y^{a_i} + D^{a_i} * \cos(\theta_k) \qquad (3)$$

The pair of $X_k^{a_i}, Y_k^{a_i}$ shows possible locations for agent a_i to go. At this stage a payoff function is needed to calculate the goodness of each location to let the agent to choose the nest one. Eq. 4 is the payoff function where based on the estimation of the walking speed in each direction and the distance to the exit, a_i can select its path.

$$\exists\, k, \frac{\left|\left(X_k^{a_i}, Y_k^{a_i}\right), E_m\right|}{W_k'^{a_i}} * \eta = p_k \rightarrow \forall k' \neq k, \forall\, m, \frac{\left|\left(X_{k'}^{a_i}, Y_{k'}^{a_i}\right), E_m\right|}{W_{k'}'^{a_i}} * \eta > p_k \qquad (4)$$

Eq. 4 not only selects the next movement location $(X_k^{a_i}, Y_k^{a_i})$, but also it determines to each exit door (E_m) the agent is headed. The η is an uncertainty parameter, which has a random value. It adds ambiguity to the decision-making system, which seems rational for a panic evacuee. The η is a random annealing parameter, where it starts with a big weight and during the time the weight decreases. Thus, there are two uncertainty parameters in the payoff function. The first one (η) is the related to the doubt of evacuee to select which route to exit. The second one ($W_k'^{a_i}$) is the estimation of evacuee of how fast can left the compartment using different exits and the congestion of the crowd.

On applying the agents' decision to the game and going to the next round of the game, several update functions are needed. Eq. 5,6 shows the update function for η, which starts with a big value and it is reduced during the time.

$$\eta^{max} = \begin{cases} 1 & \eta^{max}/2 < 1 \\ \eta^{max}/2 & Otherwise \end{cases} \qquad (5)$$

$$\eta = rand(\eta^{max}) \qquad (6)$$

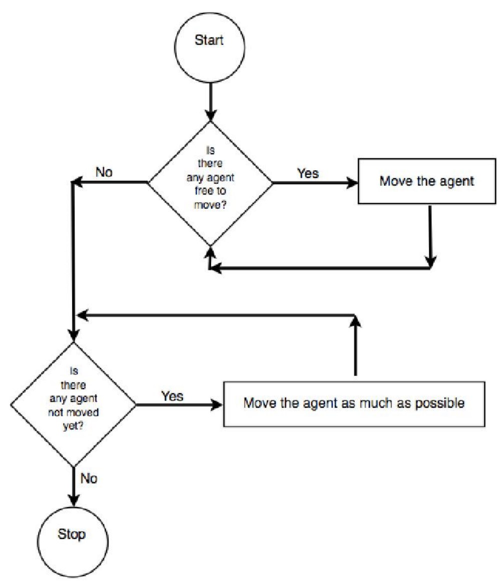

Figure 1. Agent Movement Update

The updating function of the agent movements is presented in Figure 1. In this function first those agents who are free to move will be transferred to their new location. These agents do not have any other agent in their path toward the new location. Then, it will be checked again that is there any other agent, which now is free to move. This is a loop until no other agent can move completely to their destine location. In the second step, agents will be moved toward their destine path up to the location which may create the conflict. This is more like a congestion of people where although they can move fast, they only can walk up to they get close to the inform person.

5. Simulation Environment

In order to simulate the proposed agent based evacuee modeling, two scenarios have been used. In the first scenario all evacuees are positioned randomly inside a map showed in Figure 2. There are two exits for this map and normally they are supposed to close the exit door which closer to them. However, in the proposed model it is expected that evacuees change their decision based on the online events and congestions inside the compartment. Scenario no. 2, nevertheless, has more exciting feature. In this map, evacuees firstly choose a close exit, which is a natural selection. However, the evacuees will learn that this is not a fast way out as at first was predicted. Thus, it is expected that they change their mind and move toward the alternative path. The placement of agents are just in zone A and zone B as shown in Figure 3.

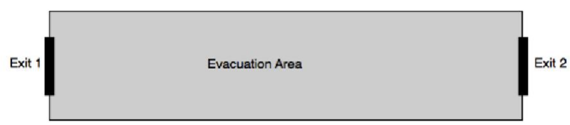

Figure 2. Scenario 1 of Evacuation Simulation

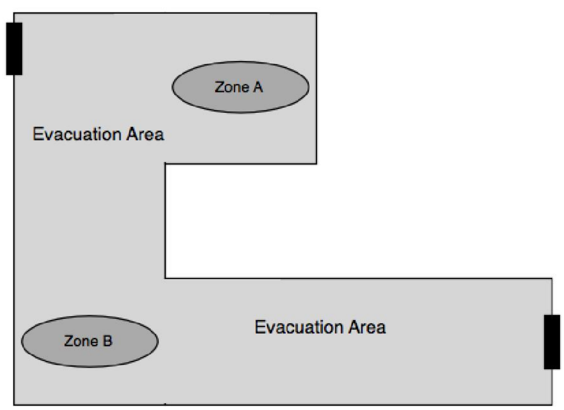

Figure 3. Scenario 2 of Evacuation Simulation

In the simulation setup from 50 to 200 agents have been deployed in the evacuation area. The simulation has been run repeatedly until all evacuees left the building. The area of map in scenario 1 is 100*10m^2 and in scenario 2 zone A is 20*20m^2, the middle part is 20*60m^2 and the lower part is 20*80m^2. The uncertainty parameter η^{max} has been set to a range of values from 10 to 100 to explore the effect of it in evacuation. The simulation has been run 10 times for random evacuee placement and the average values of evacuation time has been reported in charts.

6. Results and Discussion

Before starting the experiments, the best value of η^{max} for this simulation setup has been explored. For high values of η^{max}, agents oscillate on their location for while until each get to a verdict to where to go (by decreasing the value of η^{max}, agents will be more certain on where to go). Nevertheless, the lowest possible value for η^{max} removes one of the chances of evacuees to show the panic behavior. As there is no constant scientific value for η^{max}, by observing the behavior of agents the value of 45 has been selected as the best one for having both panic mode and not oscillating much.

Figure 4 shows the evacuation time of two decision making algorithms. In the first one, the evacuee just selects the closes exit and closest path to it for evacuation. In the second one, the evacuee uses the proposed uncertain decision making model to decide which exit is better to choose.

As it is shown in Figure 4, the uncertain decision-making model has lower evacuation time compared to certain decision-making model where there is low amount of congestion in the environment. However, with high amount of congestion there is not much difference between two methods, where uncertainty will not help that much to reduce the evacuation time.

Figure 5 is the result of running the same simulation setup on map 2. The results show that in this specific scenario, where there is low amount of congestion, the difference between two algorithms is not that much, while with higher amount of congestion, the uncertainty decision making model has better evacuation time. It this scenario, after facing to evacuees from zone A, some of the agents in zone B changed their way to the second exit and that made the evacuation much faster.

The result of this research is not about proposing an algorithm for evacuation with better evacuation time. This study showed that adding the uncertainty to the agent behavior would cause a different evacuation time comparing to certain models. As long as the uncertainty is attached to human behavior, especially in panic mode, the evacuee modeling without considering it, may not produce real results on evacuation modeling.

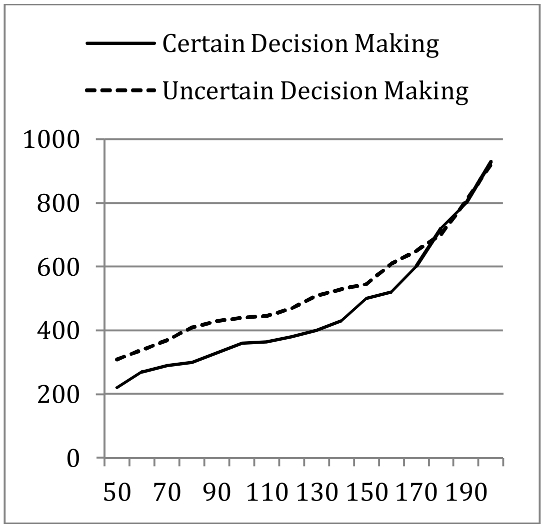

Figure 4. Using Certain Decision Model Compared to Uncertain Decision making Model in Building Evacuation Time in Scenario 1

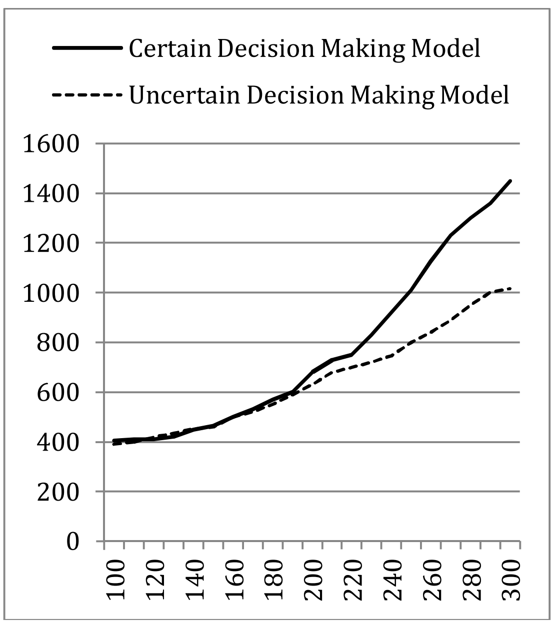

Figure 5. Using Certain Decision Model Compared to Uncertain Decision making Model in Building Evacuation Time in Scenario 2

7. Conclusion

The problem of finding the best ways for evacuation is usually implemented and tested by simulation environment, which are cheaper and more accessible to researchers. Nevertheless, the reality of the results of these simulation environments is on debate. Modeling the evacuee's behavior has been practiced by other researchers using adding more and more features to the simulation to make it as much as possible close to a real panic evacuee. However, the uncertainty of the evacuee has not yet included in current research works. In this paper, using game theory and agent-based modeling, an uncertain decision-making model for evacuee is proposed. An evacuee has a panic parameter (η^{max}), which can be increased or randomly assigned based on the various scenarios. The result of this study shows that the uncertainty of evacuees can increase the evacuation time or decrease it. This is highly related to the building map and the simulation scenario. But what is certain is that the result of uncertain decision-making model is not the same as certain decision-making models. As long as uncertainty is attached to human souls, not adding this feature to evacuation simulations can create unreal results of evacuation time.

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