Evacuation Simulation with Guidance for Anti-disaster Planning

Masaru Okaya and Tomoichi Takahashi

Meijo University Shiogamaguchi 1-501, Tenpaku, Nagoya, Japan, 468-8502
m0930007@ccalumni.meijo-u.ac.jp, ttaka@ccmfs.meijo-u.ac.jp
http://sakura.meijo-u.ac.jp/ttakaHP/Rescue_index.html

Abstract. Crowd evacuation simulations are useful tools for analyzing and assessing the safety of building occupants. Agent-based simulations provide a platform for computing individual as well as and collective behaviors in crowds. During an evacuation, it is well known that trained leaders or evacuation guidance play a key role in saving human lives. In this paper, we propose an evacuation simulation system where agents are guided by evacuation orders from authorities. The simulations captured typical behaviors observed during crowd evacuation. For example, the total evacuation time was reduced when most of the agents followed the guidance, although the evacuation times of individual agents were different. When a specific agent is involved in the movement of other agents to a different destination, the evacuation takes a longer amount of time. The simulation appears to depict real-life situations well, which shows that simulations can be a useful tool to estimate evacuation situations prior to emergency evacuation drills.

Keywords: Evacuation, Guidance, BDI model, Disaster prevention planning.

1 Introduction

In the aftermath of Hurricane Katrina and the September 11 attacks, evacuation simulations have been explored for their potential in decreasing the amount of damage resulting from disasters, and in particular, saving human lives. There are different types of evacuation behaviors, and several factors exist that might influence the amount of damage and degree of injury incurred. The Great East Japan Earthquake that occurred on March 11, 2011, along with the resulting tsunami, caused serious damage and injury. During this disaster, teachers guided their students to specific locations that they thought were safe. During the evacuations, some teachers were told that their destination was not safe, and therefore, they guided their students to another location. However, in some instances, they did not have enough time to reach their new destination.

Evacuation guidance has an important influence on evacuation behavior. Guidance from well-trained leaders can facilitate efficient evacuation [1]. The evacuation might suddenly change when evacuees receive different information from

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Fig. 1. Types of disasters that can result in change in evacuation behaviors. In the case of the WTC attacks on 9.11, many of the occupants escaped from the buildings. In the case of the Great East Japan Earthquake and tsunami, many people moved to a higher spot.

beliefs that they have, for example, by seeing that other evacuee groups move to different refugees or by reading exit signs that indicate other directions. Evacuees must then decide whether they continue their actions or trust the new information and change the actions. In the above example of the Great East Japan Earthquake, the teachers changed their destination when they heard that tsunami was coming.

In this paper, we propose an agent-based evacuation simulation system that guidance information is announced to agents. The guidance is implemented as communication between authorities and communication among civilians. The remainder of this paper is organized as follows. Related works are introduced in Section 2. Section 3 describes the architecture of the evacuation system, which comprises the belief-desire-intention (BDI) model that represents the mental status of the agents, and crowd behavior models in which evacuation information is considered. The simulation scenarios and results are discussed in Sections 4 and 5. Finally, a summary is provided in Section 6.

2 Related Works

The purposes of an evacuation simulation are to assess the evacuation time and provide important information for improving an evacuation. To assess the evacuation time, a detailed analysis of the behavior during an evacuation is required. National Institute of Standards and Technology (NIST) organized evacuation situation of WTC disaster through interviews and questionnaires. They simulate the evacuation situation of WTC with EXODUS, EXIT89, Simulex and ELVAC. Table 1 shows the issues discussed in the NIST report and comparison to actual works [2]. These issues can be categorized according to the agent level.

2.1 Individual Agent

At this level, only the agent's own properties affect their actions.

Table 1. Issues of Evacuation Simulation in NIST report

Agent level	Issues	EXODUS	EXIT89	Simulex	ELVAC
Individual	Individual travel speed	✓	✓	✓	✓
	Physical limitation	✓			
Interactive	Psychological elements				
	Communication among evacuees				
Social	Evacuation delay	*	*	*	
	Group formation				
	Evacuation guidance				
	Information seeking				

*some of the issue are taken into consideration.

Individual Travel Speed Model: It is well known that congestion of human flows occurs at emergencies. For example, when they evacuate though a narrow space, rescue teams rushing to a building may collide against people who are evacuating from the building, and at staircase landings where people from the upper and lower floors merge together. Helbing et al. proposed a particle model that can simulate these types of situations [3].

Physical Limitation: Various types of obstacles can be encountered in disaster situations, such as debris, smoke, heat, and water. These obstacles pose a threat to safety and prevent a smooth evacuation. The chosen evacuation destination and route can also affect the behaviors of evacuees. In addition, some people may stop to rest during evacuation.

2.2 Interactive Agent

At this level, their surroundings and their state of mind can affect the actions of evacuees. They may also communicate and share information. Agent-based simulation (ABSs) provide a platform for computing individual and collective behaviors that occur in crowds [4]

Psychological Elements: Some people who do not begin evacuating immediately after emergencies occur may evacuate when they see others heading for refuge or loud noises at the disaster sites can make them anxious. The psychological status and agent knowledge on emergencies affect the choice of actions [5]

Communication Among Evacuees: Psychological factors can also influence the behaviors of evacuees, including their walking speed or communication with other victims. One such communication is when a person urges others in the area to evacuate.

2.3 Social Agent

The social agent is related to behaviors related to a social context or common sense of their community.

Evacuation Delay: An evacuation delay occurs when evacuees perform a number of activities before they start evacuations. These activities include gathering personal belongings, milling with other occupants, seeking additional information, and calling family members or friends. These activities may delay the start of their evacuation.

Group Formation: Guidance from well-trained leaders allows an evacuation to flow smoothly [6]. Schools drill their students to follow the instructions of their teachers and evacuate together. At the time of a disaster, people may evacuate under various scenarios, and various factors in these scenarios can result in people forming or breaking away from a group.

Evacuation Guidance: During the WTC disaster, announcements affected the evacuation behaviors of the building occupants. Proper announcements save lives, whereas incorrect announcements can increase the amount of damage resulting from a disaster. The behaviors of occupants will be changed how well information is gathered to a rescue headquarter and how well guidance is announced.

Information Seeking: People unfamiliar with the building will want to know how they can exit. They will look for iconic warning signs, exchange information with people nearby, or follow other persons who appear to be evacuating. The sensor data change the metal state, and sometime make them anxious. The perception abilities or behavior patterns of evacuees change according to their psychological states.

Recently, human relationship among agents has been taken into consideration in MAS [7] [8]. Evacuation guidance that changes the behavior of agents is strongly linked to evacuation efficiency. These behaviors are not considered enough in existing researches. In this paper, we focus on the effect of guidance on evacuation. We assume that an evacuation simulation should be used for assessing the effectiveness of evacuation guidance.

2.4 Significance of Evacuation Guidance

Methods used for receiving evacuation guidance include broadcasts, voice guidance, and electric signs. Each method of communication has a different effect. Evacuation guidance is important for following reasons. An evacuation simulator should have the ability to take these into consideration.

Evacuation Guidance for Visitors: At a large event site, most of participants are less familiar with the place than occupants. Guidance such as evacuation routes should be properly provided to them.

Recognition of Danger: In WTC disaster, most of occupants start to evacuate after gathering personal belongings. It means that they have not noticed the immediate crisis of the disaster. Making the danger clear changes their psychological status, and they recognize need of immediate evacuation.

Evacuation Guidance for Efficient Evacuation: Phased evacuation, under certain circumstances, moves occupants most at risk to a place of relative safety much more quickly and with less total impact upon building tenants than full building evacuation. The phased evacuation had been carried out during the WTC disaster.

Evacuation Guidance According to the Situations: In most cases, the occupants of a building know the location of the evacuation site and the escape route. Evacuation guidance is important when the situations change or something unexpected happens, such as an evacuation route being rendered impassable by rubble. The evacuees might receive differing or conflicting guidance. It can be assumed that an authority knows the appropriate evacuation routes more than a civilian during a disaster situation. Evacuees naturally prefer to act on information heard directly from an authority rather than on information from messages displayed on bulletin boards. They then have to act either on the new information or on the existing guidance. Furthermore, there are many different types of evacuation signage used.

3 Evacuation Guidance and Behavior Models

3.1 Language Model and Loss of Data in Communication

It is assumed that evacuation guidance will be spread among evacuees. The evacuees might tell and ask others some information. The evacuation message contains information regarding to the evacuation destination and an appropriate evacuation route. They may be secondhand information.

Some information broadcast over a loudspeaker might not spread to all evacuees by the noises of surroundings or the damaged announcement system. Disasters can disable the emergency communication systems in buildings. When an evacuee hears only a portion of the evacuation guidance, the evacuee might misunderstand some of the contents. Rumors also belong to this type of communication. Some civilians might therefore prefer to trust only information from an authority figure. Others will trust their neighbors or heed messages sent from their families.

3.2 BDI Model Representing Psychological Status

The evacuation guidance whether it is complete one or partial one, they change their psychological status. The status of agents affects the behavior of their evacuations and it can be categorized as “awareness of danger”, “strong awareness of danger”, or a “normal state”. The degree of awareness of danger differs among different people. These differences influence their behaviors, such as gathering their personal belongings or immediately fleeing the area. Belief-Desire- Intention (BDI) model is adapted to represent such behaviors.

Belief: An awareness of danger is represented as Belief in the BDI model. For instance, the belief of an evacuee will be generated when he/she senses danger or hears evacuation instructions. In the case of an earthquake, all agents share the belief that a large shaking occurred. A belief in the “awareness of danger" or "strong awareness of danger" will be generated as a response to the mindset of an agent. Some agents who do not feel danger might do so when they hear evacuation instructions.

Desire: Most people are in the middle of an activity when a disaster occurs. They may have the desire to finish the activity. Of course, they may have desire to shirk away from the risk. The agent thus has to choose a desire when they have multiple options.

Intention: Most people are doing an activity, which they will finish in some minutes. An agent might have intention to evacuate.

4 Evacuation Scenarios and Simulations

4.1 Prototype System and Agent Behavior Model

Figure 2 shows the architecture of our system. The agents in the left part send their own properties to the crowd simulator at the start time and to their targets during each sense-reason-action cycle. The target is the position according to their intentions which is selected by their BDI models. The crowd simulator calculates the movements of the agents using an equation. The micro simulation step of the crowd simulation, $\Delta\tau(\approx 0.1s)$, is finer than the step of sense-reason-action cycle, $\Delta t(\approx 1s)$. The results of the micro-simulation are returned to every agent along with the agent's own position and the positions of other visible agents.

RoboCup Rescue Simulation v.1 (RCRS) was used as the platform of our system [9]. The RCRS was used to comprehensively simulate agent behavior during a simulated disaster environment, and supports two types of agents: a civilian agent and an authority agent.

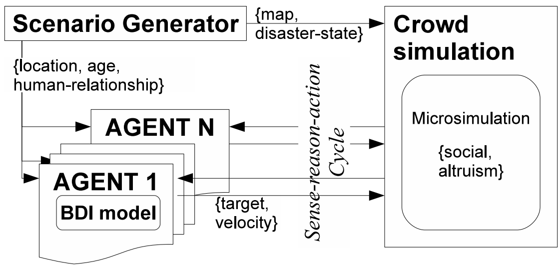

Fig. 2. Architecture of BDI-based crowd evacuation system

4.2 Communication

Message Containing Guidance from an Authority. An authority provides evacuation guidance, including information on an evacuation destination and an appropriate route to that location. Communication language is based on Agent Communication Language (ACL). The messages of evacuation guidance consist of the target person and an evacuation route. Table 2 shows evacuation instructions in which an authority guides evacuees at 1F to R1 by way of A1 and A2. The left column corresponds to the message that consists of target area and evacuation route information. The right is a message without route information and corresponds to a situation in which agents hear part of guidance.

Table 2. Evacuation guidance

complete message	message with loss of data

(inform
  :sender Authority
  :receiver Anonymous
  :time 20110311-100000
  :content
    (evacuation-guidance
      :target-area 1F
      :move A1-A2-R1
)
)
	(inform
	  :sender Authority
	  :receiver Anonymous
	  :time 20110311-100000
	  :content
	    (evacuation-guidance
	      :target-area 1F
	    )
	)

4.3 Implementation of Communication

Voice and radio were implemented as communication methods in the RCRS. Voice communication is audible to anyone near the sender. During voice communication, the distance up to which the sender can be heard is 30 m. Radio communication is accessible to any person with a radio tuned to the same channel as the sender, allowing them to hear the message. We added a communication protocol with evacuation guidance messages through voice communication.

5 Simulation Scenarios and Results

We simulated three scenarios including evacuation guidance. Situations in which the agents hear a portion of evacuation guidance was simulated.

5.1 Simulation Scenarios

Figure 3 shows a building at our university. 400 people are evacuated from the building, which has 2 stairwells and 2 exits. Table 4 shows the three scenarios. Differences of scenarios are with/without evacuation guidance, agent types, with/without loss of communication. Without the evacuation guidance, the entire agent normally goes out of the front entrance because they do not know the emergency exit. Authority agent announces evacuation guidance after 5 minutes

Table 3. Evacuation guidance: contents are different for each floors

Stair	Content of evacuation guidance
1F	exit
2F	emergency stair [2F-1F] - emergency exit
3F	stair [3F-1F] - exit
4F	emergency stair [4F-1F] - emergency exit

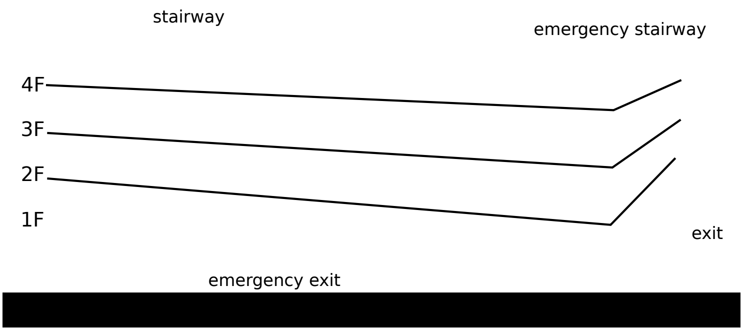

Fig. 3. Simulation map

later with building broadcasting. Contents of the guidance differ according to floors. Agents who are on the first and third floor use front stairway and front entrance, agents who are on the second and fourth floor use emergency stairway and emergency exit(Table3).

Three types of agent were implemented.

A (instant evacuation) This agent feels anxious after feeling a large shaking.
B (evacuation after tasks) This agent does not feel anxious after sensing a large shaking. This agent evacuates after a certain activity. This agent feels anxious when hearing the evacuation guidance.
C (emergent evacuation) This agent does not feel anxious after sensing a large shaking. This agent does not evacuate after a certain activity. This agent feels anxious when hearing the evacuation guidance.

Table 4. Simulation scenarios

Scenario	Guidance	Agent type	Communication
1	✓	B	no loss
		B	no loss
2	✓	A+B+C	no loss
		A+B+C	no loss
3	✓	A+B+C	loss
		A+B+C	loss

Cases of loss of communication have been simulated. The rate of loss in the guidance messages was decided according to reports of the Great East Japan Earthquake [10]. 82 % percent of agents who hear the guidance will hear the announcement of the guidance, and 82 % percent of the agent listen to the evacuation route information in the guidance and recognize the danger. So 56 % of agents start to evacuate.

5.2 Simulation Results

Figure 4 shows the simulation result of Scenario 1. Totally evacuation time in case of scenario with guidance is shorter than that of scenario without guidance. Furthermore, in case of evacuation with guidance, it takes 1600[s] for all agents who used emergency exit, while it takes 900[s] for all agents who used front entrance. It means that more efficient guidance can be considered.

Figure 5 shows comparison of simulation results of Scenario 1, 2 and 3. In case of evacuation without the evacuation guidance of Scenario 2 and 3, some agents who did not recognize the danger did not evacuate. In a case of Scenario 3, agents who came out of the front entrance are more than the others. It is because that agent who did not hear the guidance decided his/her intention by themselves. As a result of that, it took them more time evacuate than the others who heard the guidance.

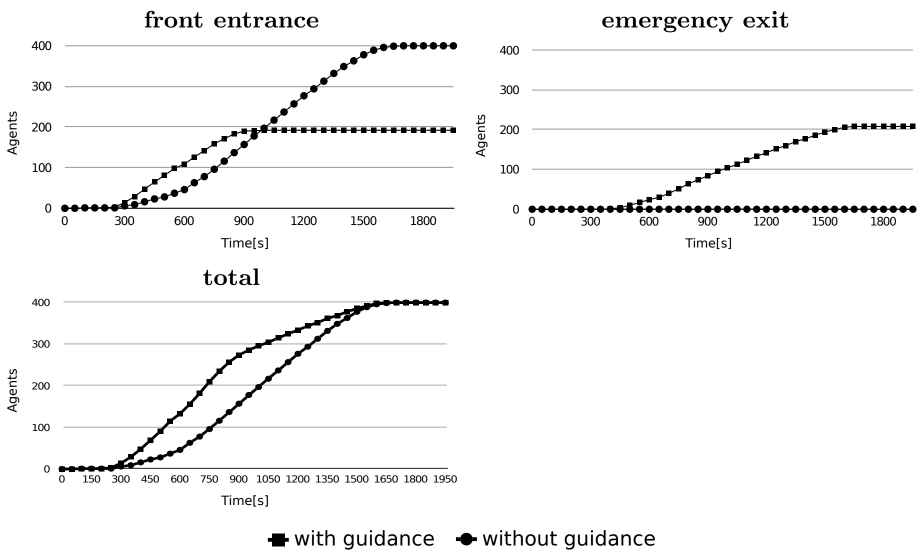

Fig. 4. Simulation result of Scenario 1. Agents who came out of each of the exit. And total agents who exit the building.

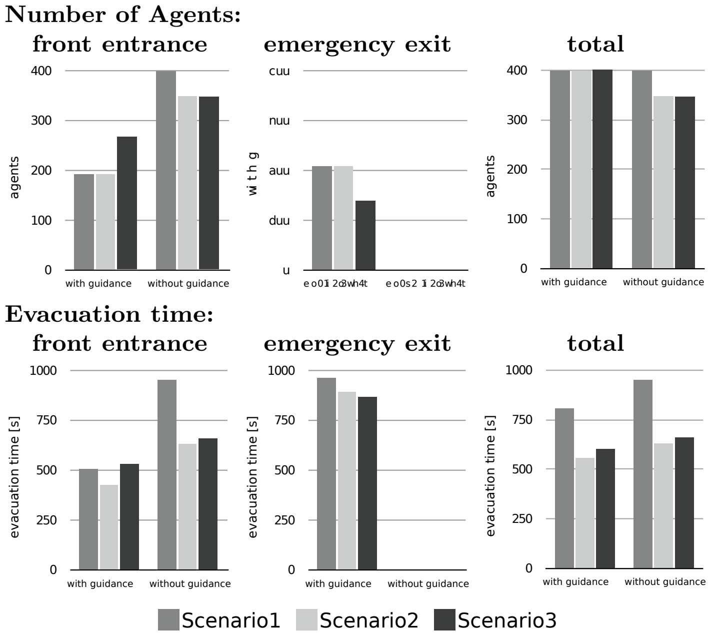

Fig. 5. Simulation result of Scenario 1, 2 and 3

6 Summary

The analysis of building evacuation has recently received an increasing amount of attention as people are keen to assess the safety of occupants. Agent-based simulation systems, such as RCRS, not only provide a platform for computing individual and collective behaviors in crowds but also their communication model supports the announcement of evacuation guidance to agents. The guidance affect the behaviors of agents, especially the delay in evacuations are closely to human lives.

In our system, the announcement of guidance is implemented as communication to agents. And the messages are modeled as a form of ACL. Agents who hear the guidance partially are modeled as they receive missing messages. When agents do not hear clearly the guidance, they behave different from ones who hear the entire message. As a result, our system can simulate the behavior of agents who do not follow evacuation guidance. We also use BDI model to represent the psychological status of agents. In our simulation system, the changes of BDI states that are caused by sensor data affect their evacuation behavior at emergencies. This makes it possible to simulate the behavior of evacuation with guidance information.

These results demonstrate that our simulator have the ability to take these scenarios which contains evacuation guidance into consideration and reconstruct these situations.

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