Effect of Guidance Information and Human Relations Among Agents on Crowd Evacuation Behavior

Masaru Okaya and Tomochi Takahashi

Abstract Evacuating people during emergency situations or natural disasters is a complex task. In simulation systems, evacuees have been treated equally, or at least physical difference such as the evacuees' ages and genders are considered as parameters of simulations. We believe the content of guidance information influences their mental states, as well as helps to alleviate anxiety about their own and their family's safety, and leads to evacuation behaviors based on their situations. The effect of guidance information as it relates to family relationships among agents is simulated with our ABS evacuation simulation system. Three evacuation scenarios involving different types of disasters are simulated and the results are discussed.

Keywords Simulation • Phased evacuation • Mental state • Evacuation guidance

1 Introduction

Evacuating of people during emergency situations or natural disasters is a complex task. It is difficult to conduct physical experiments that involve many people and real environments, or to make effective plans for predictable situations based on the data of past disasters. Disaster simulation systems are employed to develop prevention plans for disasters and to test the plans. In simulation systems, evacuees are treated equally, or at least physical differences such as the evacuees' ages and genders are considered as the parameters of simulations [1].

M. Okaya (✉) • T. Takahashi
Department of Information Engineering, Meijo University, 1-501 Shiogamaguchi, Tempaku, Nagoya 468-8502, Japan
e-mail: m0930007@ccalumni.meijo-u.ac.jp; ttaka@meijo-u.ac.jp

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We know how people evacuated during disasters from reports published by those in authorities. They involve the following phenomena: people begin evacuation based on their preset circumstances; announcements from those in authority are not always clearly heard; and people communicate and share information among themselves and adjust their actions and behaviors accordingly. The phenomena present features that are addressed by crowd simulation systems.

We focus guidance information and human relations on agents involved in the disaster to control the behaviors exhibited during evacuations. The guidance information is broadcast by those in authority to achieve a more efficient evacuation process. As a result, better evacuation results in less damage caused by the disasters. An agent-based crowd evacuation simulation is proposed in this paper; the features of the systems are as follows: the guidance information is presented as a method of communication to and among agents, and their actions emerge from BDI (Belief-Desire-Intention) models. The guidance information is fed to the BDI models so that human relations factors of the agents are represented.

Background and related works are described in Sect. 2. Section 3 introduces our simulation system, which can provide guidance for agents to rely on during their evacuation. The agents behave according to their circumstances. Three scenarios of different evacuation types are shown. The simulation results are discussed in Sect. 4, and the summary is described in Sect. 5.

2 Background and Related Works

Disasters can occur anywhere and anytime, and can result in serious damage. Several disasters that caused serious damages in this decade immediately come to mind; for example, the September 11, 2001, attacks on the World Trade Center (WTC), the East Japan earthquake, along with the resulting tsunami, that occurred on March 11, 2011, and so on. Although they were different types of disasters and different types of evacuation behaviors were shown, evacuation simulation is one of the key factors necessary to decrease the damages that result from emergencies.

Bandini et al. cited three future research topics on crowd simulation: data acquisition using new technologies, such as GPS and RFID, validation techniques advancing beyond empirical studies, and the integration of psycho/sociological consideration in crowd models [6]. Pelechano presented an agent-based simulator for which both physical interactions and communication between individual agents are introduced [7]. A detailed report on occupant behavior in the World Trade Center (WTC) disaster has been published by the National Institute of Standards and Technology (NIST), and a related study has been carried out by Galea et al. [2, 4]. Survey results on evacuation behavior during the East Japan Earthquake are available as conference documents to the Japanese Government [5].

3 2001 World Trade Center

NIST organized evacuation studies of the WTC disaster through interviews and questionnaires. In the reports, the behaviors of people differed between WTC tower 1 and tower 2, and these also differed among people who had experienced the 1993 WTC bombing incident. Some occupants started to evacuate as soon as WTC1 was hit, while others performed specific activities that they wished they had performed in 1993, such as calling home and the like. The following phenomena were reported in the report.

1. Rescuers who entered a building moved in the opposite direction of occupants who were exiting the building. These movements resulted in human interactions during the evacuations. Family-minded human behaviors, such as parents searching for their children, may also have caused similar interactions during crowd evacuation.
2. Evacuation guidance information leads people to evacuate safely and efficiently. While some people begin to evacuate immediately after hearing evacuation guidance information, others may continue working if the guidance is not clearly announced. In a worst case scenario, others may not hear the guidance information.

4 2011 Great East Japan Earthquake

After the earthquake, announcements of the impending tsunami attack and requests for quick evacuations were broadcasted throughout towns by various administrative offices. In the report, people who heard the announcements are categorized into three types: (1) individuals who evacuated immediately upon hearing the announcement; (2) individuals who evacuated after first completing tasks that they had been working on, and (3) individuals who evacuated when they really felt that their life was being threatened [5].

3. Teachers guided their students to a refuge after they heard the tsunami warning along with the earthquake warning. During the evacuation, someone on the way to the refuge informed them that the refuge was not safe, so they went to the other refuge. However, they did not have enough time to make it to the second refuge.

NIST assessed the evacuation time from the WTC and analyzed the behavior of people during the evacuation using the following simulation systems: EXODUS, EXIT89, Simulex and ELVAC [2]. They reviewed the features of the egress models of simulators [1]. Although the above three points are important features of evacuation behaviors, the features have not been supported by the existing evacuation simulations.

We believe getting information guidance information to evacuees is one of the key factors that affect their evacuation behaviors. Table 1 presents the issues

Table 1 Features of models in evacuation simulations and their purposes

Model of evacuation behaviors
Traffic simulation
Travel speed model
Congestion model
Counter flow, obstacle model
Space model
Grid/network/continuous space
2D or 3D model
Actions involving individual behavior
Sensing model
Delays in evacuating
Receiving information
Action model
Selfish/altruistic actions
Information seeking task
Choosing and locating exit routes
Group behaviors
Leadership/ human relations
Sharing information
Purposes of simulations
Risk management
Preventions planning
Experience and training rescuer/rescuee

discussed in the report. The '-' marked features are important in simulating following process: the contents of guidance influence evacuees' mental states and affects their anxiety levels concerning their own and family's safety, which in turn leads to evacuate behaviors based on their individual situations. The simulators in the reports do not have the functions of announcing evacuation guidance information to occupants, and presenting their human relationship that affect the behaviors of evacuation.

5 Simulation with Guidance Information for Evacuees and Human Relations Among Agents

5.1 Features of Our System

There are various scenes for rescue and search operations during disasters, and evacuation behavior is different for each scene. Figure 1 illustrates typical scenes that may occur when disasters strike are, for example,: (1) the disaster-prevention departments broadcast emergency announcements; (2) people exit rooms and proceed to the ground level using the stairs and elevators; (3) people evacuate to safe places; and (4) rescuers start their operations.

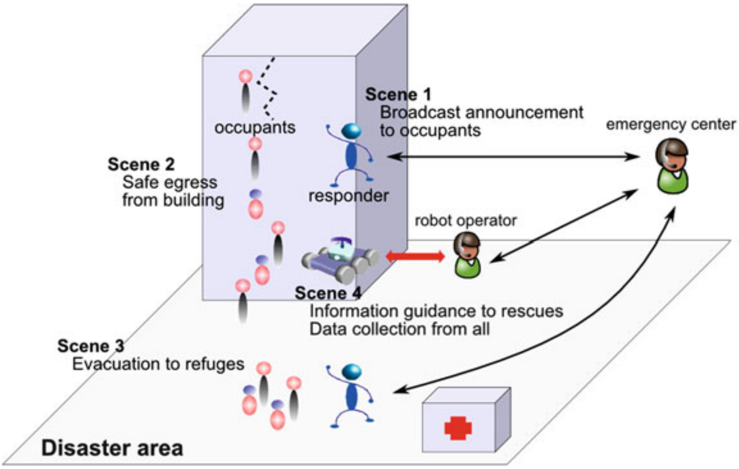

Fig. 1 Emergency scene and evacuation scenarios

We propose a crowd evacuation system for which human relations among agents and guidance announcements during emergencies are taken into consideration. Features of the system are as follows:

1. During emergencies, people behave differently than they normally would. Their behaviors are affected by mental conditions. A BDI model is employed to show how agents select their actions based on particular situations during the sense-reason-act cycle.
2. Some people engage in altruistic behavior. For example, parents may take care of their children at the risk to their own safety. They move against the major flow of other people to reach their child. The counter movement may become a blockade to others who are hurrying to refuges.
3. During disasters, there are two types of information propagations: announcements from those in authority to evacuees and communication among evacuees. They are introduced as communication among agents during simulations.

5.2 Agent-Based Simulation System

Figure 2 shows the architecture of our agent abased system.

5.2.1 BDI Model Representation of an Evacuee State

During emergencies, people feel unusual events are taking place and, become anxious about their own safety and that of their family and take various actions

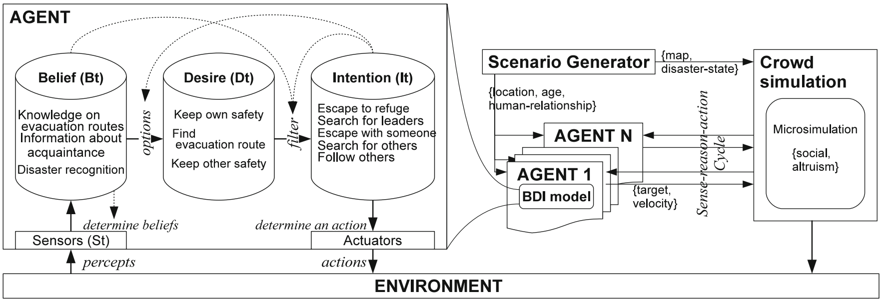

Fig. 2 System architecture of ABS evacuation system

based on information received. Some people may only trust information that is disseminated by an authority figure, while others will trust their neighbors or heed messages sent from their acquaintances. During the Great East Japan Earthquake, it is reported that approximately 30 % of people began their evacuation by taking advice from acquaintances who themselves had taken the evacuation guidance information seriously [5].

We categorize these behaviors as an awareness of danger. The degree of awareness of danger differs among different people, and these differences influence their behaviors when they start evacuating. The BDI model has been adapted to represent such behaviors.

- Belief (B_t): $B_t = \mathit{belief}(S_t, B_{t-1})$
  When a person feels the shock of the earthquake or hears evacuation instructions, he/she considers his/her safety to be more important than other jobs. Some agents who do not feel they are in danger might feel differently when they hear evacuation instructions. The awareness of danger as it relates to beliefs changes according to the mindset of the agent.
- Desire (D_t): $D_t = \mathit{option}(B_t, I_{t-1})$
  The changes in beliefs affect desires. Most people are in the middle of performing a job when a disaster strikes. They may have the desire to finish the task, or they may have other desires to keep themselves and others safe.
- Intention (I_t): $I_t = \mathit{filter}(B_t, D_t, I_{t-1})$
  Agents filter one action from suitable actions to achieve their own desires. Agents have their own preferences depending on their personality and social norms. An agent might intend to evacuate or to save an injured person.

S_t is a set of sensor data that an agent receives at time t, and B_t, D_t and I_t represent the status of beliefs, desires and intentions, respectively. B_t consists of rules of action, knowledge, and states. The differences in agent types are implemented by using different *belief, option,* and *filter* functions.

5.2.2 Evacuation Guidance Information to Agents

Authorities announce information that will help make evacuations efficient and smooth, and agents try to share information. The agent hears the evacuation guidance information as sensor data. The guidance is transmitted through two methods: (1) emergency announcements from authorities and (2) communications from other agents.

The guidance consists of the targeted persons, evacuation routes, and other pertinent information. Announcements are implemented in a form of Agent Communication Language (ACL). The following example shows evacuation instructions in which a rescuer guides an occupant on the first floor to use route `R1` byway of points `A1` and point `A2`.

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

The text announced by the rescuer may not be audible to all target agents, and some agents may not hear the complete message. These situations are simulated by two parameters in the communication protocol to agents: (a) the distance up to which the message can be heard and (b) the percentage of loss in the message.

5.2.3 Crowd Simulation on Continuous 3D Space

Agents determine their intentions at every simulation step at which they receive new senor data, and send their targets position to a crowd simulator. The crowd simulator calculates the movements of the agents in the step. The motions of the agent at one simulation step t is calculated by micro simulation using a model in that altruism force that comes from his/her own human relations and is added to a social force in Helbing's model [3, 8].

5.3 Evacuation scenarios

The following three scenarios are presented to showcase our features that traditional evacuation systems do not possess.

Scenario 1. Pairs of parent–child evacuations from campus:

Agents act according to their conduct codes or wills. Parents tend to act on their own child's behalf at the risk to their own safety. During emergencies, they

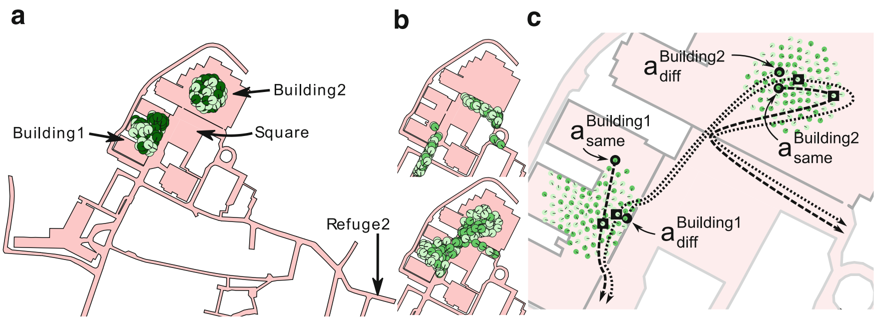

Fig. 3 Layouts of buildings and snapshots of simulations. (**a**) Layout. (**b**) Snapshots. (**c**) Trajectories of parent agents

evacuate together, and the parent goes to his/her child if they are separated when the disasters strike.

Scenario 2. Evacuations with guidance information provided by those in authority and communication among evacuees:
During an emergency, people go to a refuge. Authorities announce the location of refuges, along with routes that they assume safe. Some agents follow the guidance information, while others do not for various reasons.

Scenario 3. Phased evacuation from a library building:
Authorities of buildings prepare texts to be announced to the building occupants during emergencies. The texts may contain different messages based on the needs of people on different floors to ensure evacuees move quickly and efficiently.

6 Simulation Results

6.1 Scenario 1: Pairs of Parent-Child Evacuations from Campus

The scenario is evacuation from a campus (Fig. 3a). Fifty pairs of parents and children participated in an event that was held in two buildings on the campus. The features of the agents are as followings:

- Parent agents move autonomously and can look for exits when they have no knowledge of escape routes. They have one child and are anxious about their child
- Child agents have no data on escape routes and no ability to ask others for help. They can distinguish and follow their parents.

They are divided into two groups: 25 parent agents and 25 child agents are in both Building 1 and Building 2, respectively. They evacuate to a nearby refuge location during emergencies. Refuge 1 is near Building 1 and Refuge 2 is near Building 2.

The following three cases are simulated:

1. Parents and their children from all pairs are in the same building.
2. Agents are divided so that a parent and his/her child of 25 pairs are in the same building, and the other 25 pairs are in the other buildings, respectively.
3. For all parent–child pairs, parents and their children are indifferent buildings.

Parent–child pairs evacuate smoothly in case 1 (Fig. 2b up). In case 2 and 3, parents whose children are in the other building move to their child (Fig. 2b bottom). The lines in Fig. 2c show the trajectories of parent agents who evacuated last from both buildings in case 3. a_{same}^{*}s and a_{diff}^{*} are parents whose children are in the same buildings and different buildings, respectively. The trajectories of a_{diff}^{*} show that parents go to the other building, meet their child, and escape together, respectively. The parents' movements cause congestion in the square and in the entrances to the buildings. The congestion incase 3 is more of a problem than in case 2, and it takes more time for people to evacuate from campus.

6.2 Scenario 2: Evacuation with Guidance Information from an Authority and Communication Among Evacuees

The second scenario is modeled after a tragedy that happened at Ookawa Elementary School during the tsunami that occurred along with the East Japan Earthquake. Most of the students were engulfed by the tsunami and died, even though they had heard the tsunami warning 1 h before it struck. When the earthquake occurred, all students evacuated to the ground floor. The school was located 5 km from the sea, so they did not expect the tsunami to reach the school and did not have a specific manual for evacuation. Teachers talked and decided that they would go to Refuge 1. During their evacuation to Refuge 1, they knew that the tsunami was coming and that Refuge 1 would not be a safe place; therefore they decided to go to Refuge 2, which was located on a hill. Unfortunately, it was too late.

We tested two evacuation cases.

Case 1 Agents receive guidance information from an authority only (Fig. 4a). Some evacuees follow the guidance information from the authority, while others do not.

Case 2 Agents receive guidance information from the authority and share the information through communication. Some evacuees meet others who go to refuge 2 by following the authority's guidance information. Some of the evacuees trust what the others say and change their destination before they hear the guidance from the authority.

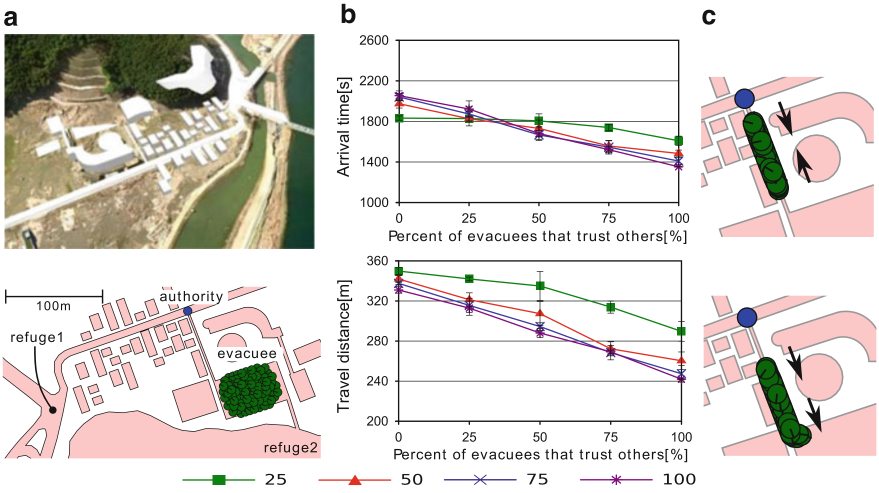

Fig. 4 Ookawa elementary school after Tsunami, results and snapshots of simulations. (**a**) Disaster area and initial state. (**b**) Simulation results. (**c**) Congestions

Figure 3b shows the travel distance and average arrival times of the evacuees arrive at Refuge 2. The X axis of the graph shows the percentages of evacuees who trust messages delivered by other evacuees. The messages are the guidance information received from the authority, and the marks on the lines indicate how many evacuees follow the guidance when they hear it from the authority. The followings can be assumed from the graph:

1. More evacuees trust the message of others, thus, the arrival time and travel distance become shorter. Figure 3c illustrates the flows of evacuees as it changes from a counter flow (up graph) to a direct flow (bottom graph), and the effects form congestion are lessened.
2. More evacuees follow the guidance information received from the authority; the same results as above are applied even when they share the information at the same rate among evacuees.

6.3 Scenario 3: Phased Evacuation from a Library Building

Figure 5 shows a library building at our university. The square footage of the library is about 2,000 m^2, and 1,400 occupants are allowed inside the building, according to the Fire Service Law. It has five stairways: two stairways run through from the fifth floor to the first floor, and four stairways run between neighbor floors. There are two exits: a front exit on the second floor and an emergency exit on the first floor.

Fig. 5 Phased evacuation from library building. (**a**) Floor layout. (**b**) Without guidance. (**c**) With guidance

The announcements are modeled for a phased evacuation according to the WTC emergency guidelines (p. 35 [2]) and the content differs according to the floors. Agents who are on the first and fourth floors are guided to egress through the stairway and go out through the emergency exit, while agents who are on the second, third and fifth floors are guided to egress from the front entrance. Without the announcement, all agents normally exit through the front entrance because they do not know about the emergency exit.

Three types of agents who responded differently to the same emergency announcement are cited according to the report of the Great East Japan Earthquake [6].

- Agent Type 1: (instant evacuation) People who feel anxious after experiencing accidents that have involved extreme shaking initiate their own evacuation.
- Agent Type 2: (evacuation after tasks) People who do not feel anxious after accidents and evacuate after completing their current activity. They do, however, feel anxious when they hear the guidance information announcement.
- Agent Type 3: (emergent evacuation) People who do not feel anxious and do not evacuate after completing their current activity, and after hearing the evacuation guidance information initiate evacuation when they become extremely anxious after receiving newly information from others.

We simulated three emergency cases, each with 100 people on each floor, for a total of 500 people who would be evacuating from the building. The differences among three cases are as follows:

1. In case 1, all agents are type 1 and initiate their own evacuation immediately at the starting time. In cases 2 and 3, each agent is either type 1, 2 or 3. Type 2 and 3 agents evacuate 5 min after they receive the evacuation guidance information.
2. The difference between cases 2 and 3 is with and without the loss of guidance information. The rates of information losses are set according to the report [2].

Figure 6 shows a comparison of the simulation results for cases 1, 2 and 3. In the case of evacuating without guidance information of cases 2 and 3, the number of agents who egress from the front entrance is less than 500. This is because some agents of type 2 and 3 agents did not feel they were in the danger and thus did not evacuate. In case 3, the case with guidance, the number of agents who exited

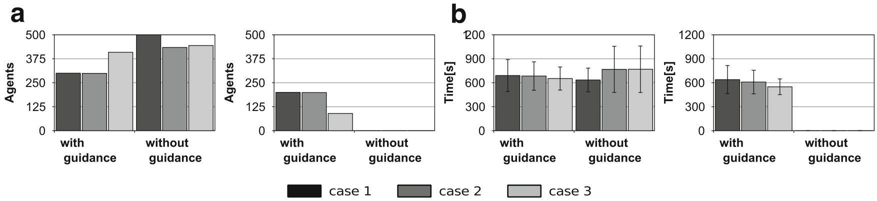

Fig. 6 Simulation results of evacuation from library. (**a**) Number of agent. (**b**) Evacuation time

from the front entrance was greater than those who exited from the emergency exit. This is because some type 3 agents, who did not hear the announcement, decided to egress based on their own BDI model. As a result, there were more people egress from the front entrance than from the emergency exit, and therefore the evacuation time was longer than the others.

7 Summary

Recently, people have been eager to assess society's safety after having experienced several disasters and the analysis of evacuation behavior has received increased attention. Agent-based simulation provides a platform for computing individual and collective behaviors in crowds.

We present two ideas; an agent behavior model presented with BDI and information propagation through communication to generate the phenomena observed in crowd evacuations. The BDI model shows how human relations among agents, the degree of trust in others' information, and the loss of text in information dissemination affect the patterns of the behaviors. The simulation results of the evacuation scenarios reveal the followings:

1. The properties of human relations and guidance information affect evacuation behaviors. The behaviors are different from those of people how much information they get from the announced guidance or from who they get the information.
2. The behaviors of some agents affect the evacuation behaviors of all agents. Some behaviors are known to cause congestion, requiring extra time to evacuate, just as in real life.

These results demonstrate that our model provides an effective simulation method of crowd behavior in emergency situations, and that test the evacuation plans and announcements of guidance information.

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