Application of an Information Transfer Model to Evacuation Guidance during Emergencies

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Abstract – Reports related to disasters such as the September 11, 2001, World Trade Center attacks and the Great East Japan Earthquake and the ensuing tsunami have provided important lessons related to human casualty reductions. One key lesson demonstrates that agents tend to respond individually during emergencies. Individuals’ responses can be categorized into three types: (1) some individuals evacuate instantly, (2) some evacuate when they hear evacuation guidance messages provided by authorities, and (3) others evacuate when they feel extreme anxiety. Evacuation announcements significantly influence human behavior during emergencies. We propose a model that illustrates the ways evacuation announcements are transferred to individuals and that demonstrates their effects on individuals’ evacuation efforts. We implemented an information transfer model in an agent-based system that included an agent communication function as well as a Belief-Desire-Intention (BDI) model. The communication function provides announcements from authorities to persons, while the BDI model represents human behavior during emergencies. Simulations of evacuations from a five-story building revealed the effects of phased evacuations when noise disrupted the provision and reception of evacuation guidance. The simulation results revealed that the dissemination of messages during emergencies is useful and supports the development and application of effective evacuations plans.

Keywords – evacuation guidance, evacuation simulation, information transfer model, human behavior

1. Introduction

Emergencies such as fires, earthquakes, or terrorist attacks can occur at any time in any location. Disaster countermeasures have been deployed in a variety of countries and regions (Perry, 1984; Kitao, 1986). Many organizations engage in emergency preparations and provide trainings to save individuals during emergencies, as well as to reduce damage during future disasters. Disaster-prevention departments of governments, buildings, and other organizations develop these training programs. During these trainings, individuals learn that they must evacuate quickly and move to safer locations. They also learn to cooperate with one another to ensure smooth evacuations from buildings.

The importance of evacuations has been reaffirmed by a number of reports related to various disasters. The September 11, 2001 attacks, the Great East Japan Earthquake (GEJE) that occurred on March 11, 2011, and the ensuing tsunami, took many lives and caused serious injuries. Detailed reports focused on occupant behavior during the World Trade Center (WTC) disaster were published by the National Institute of Standards and Technology (NIST), among other organizations (Averill, 2005, Edwin, R. G. et al., 2008). A survey examined evacuation behavior that occurred after the tsunami alarm was broadcasted during the GEJE. The results were provided in conference documents published by the Japanese Government (Japan Cabinet, 2012).

Evacuation announcements can exert significant influence on individuals’ behaviors when they begin to evacuate and exit buildings (Averill, 2005). The provision of guidance by well-trained leaders can facilitate efficient evacuation (Amanda, 2008). It can be difficult to conduct physical experiments that involve large numbers of humans in real environments. Therefore, evacuation simulations have been studied and developed. In the NIST report, simulations of the evacuation of the WTC towers.
The purpose of the simulation was to model evacuation times for a number of scenarios. During the experiment, several simulation systems (EXODUS, EXIT89, Simulex, and ELVAC) were employed. Issues related to evacuees were classified into three categories: individual, interactive, and social issues. The individual issue focused on individuals’ travel speeds and the obstacles that might hinder their egress. The systems used in the experiment that simulated evacuations addressed these parameters. However, they did not address interactive and social issues. The interactive issue focused on psychological aspects, as well as on interactions that occurred among agents during efforts to share information related to egress. For example, individuals’ behaviors, such as seeking refuge and seeking information related to their families’ safety, affected the behaviors of other individuals. The social issue focused on information related to routes to exits and methods used to provide evacuation guidance.

Agent-based simulation (ABS) provides a platform for the development of computing behaviors related to interactive and social issues (Thalmann, 2007). The occurrence of loud noises at disaster sites can increase individuals’ anxiety. ABS is used to simulate the impact of agents’ psychological status and knowledge on their choices of action (Pan, 2006). Nuria et al. showed communication between people improves evacuations rates by ABS (Nuria, 2006). They devised a scenario that focused on two types of agents: (1) leaders who help others and explore new routes; and (2) agents who might panic during emergencies that occur in unknown environments. Tsai et al. developed ESCAPES, a multi-agent evacuation simulation system that incorporates four key features: (1) different types of agents, (2) emotional interactions, (3) informational interactions, and (4) behavioral interactions (Tsai, 2011). These key features have been used to estimate evacuation times during building design processes or to develop prevention plans that might minimize damage and the loss of human life.

We believe that evacuation announcements exert significant influence on individuals’ evacuation behaviors. Existing evacuation simulations assume that individuals evacuate concurrently. However, this does not always occur (Erica, 2005). Furthermore, simulation systems do not include announcement functions that provide information during evacuations. In this paper, we propose an information transfer model that includes an announcement broadcasted to agents. The model uses an internal process that begins with the initial broadcast of the announcement to agents and continues with the initiation of the evacuation. The agent-based simulation system replicates evacuations from a five-story building. This paper is organized in the following manner: Section 2 presents lessons learned from past disasters. Section 3 describes human behavior during emergencies. We present our information transfer model and agent-based simulation system in Section 4. Section 5 describes evacuation simulation scenarios and the results of our simulations. Section 6 provides a summary of our results.

2. Lessons learned from past disasters

A number of studies have focused on human behavior during past disasters. NIST examined occupant behavior during the attacks made on the WTC buildings. The cabinet office of Japan also reported on individuals’ evacuations during the GEJE. Three common issues were discovered:

- Some individuals evacuated immediately when the disasters occurred. However, others failed to evacuate, even though they heard emergency alarms provided by authorities. Individuals used several methods to evacuate from areas or offices (Japan Cabinet, 2012). First, in the instant-evacuation category, individuals became increasingly anxious when emergencies occurred. Second, in the evacuation-after-tasks category, individuals failed to evacuate immediately. However, they did evacuate when they heard evacuation guidance provided by authorities. Third, in the emergency-evacuation category, individuals evacuated when they felt extreme anxiety.

- The evacuation-after-tasks and emergency-evacuation categories involve individuals who had family members located in remote areas, individuals who attempted to contact their families by phone, and individuals who continued to work because they believed they were safe. The provision of alarms and subsequent guidance by authorities changed the behaviors of individuals in these categories.

- Once individuals understood their situations and received information related to the emergencies, building layouts and concerns about their families’ safety affected their evacuation behaviors. They applied information provided in announcements. They also benefited from communications with other individuals.

It is interesting to note that individuals’ behaviors during these two disasters were similar to the behaviors of individuals during a flood in Denver, U.S.A. on June 16, 1965, even though communication methods have changed during these fifty years (Drabek, 1968). Approximately 3,700 families were suddenly evacuated from homes. The family behaviors during the flood that occurred following the provision of warnings were categorized as follows: (1) some families evacuated immediately, (2) other families attempted to confirm the threat of disaster, and (3) some families ignored the initial warning and continued with routine activities.

The NIST report indicated another issue that should be considered in models of evacuation behaviors. With respect to the WTC attacks, WTC1 and WTC2 were similar in size and layout. During the attacks, similar numbers of individuals inhabited both buildings. Individuals in both buildings began to evacuate when WTC1 was attacked. WTC2 was attacked 17 minutes later. At that time, about 83% of survivors from WTC1 remained inside the tower. About 60% of survivors remained inside WTC2. Section 10.1 of the NIST report provides changes in those percentages. Differences in evacuation behaviors between
the two buildings resulted from interactive and social issues. These issues involved leadership or announcements of evacuation guidance. Typical guidance announcements are provided in the Appendix.

During large earthquakes (e.g., the earthquake that occurred in Hanshin Awaji, Japan in 1995 and the earthquake that occurred in Eastern Sichuan, China in 2008) many people died when buildings collapsed. The GEJE and the Indian Ocean earthquakes occurred in 2004. The tsunamis that followed these earthquakes caused more deaths than the earthquakes themselves. Prior to the impact of a tsunami, a brief period transpires during which individuals can evacuate to safe places. Table 1 illustrates the time sequence for the provision of information during the GEJE. A period of about 45 minutes transpired prior to the tsunami’s full impact. Once individuals realized they had 45 minutes to escape, the majority was able to do so.

3. Human factors on evacuation behaviors

3.1. Definition of evacuation process and time

The International Organization for Standardization (ISO) published a technical report that provides information related to occupant behaviors during evacuations caused by a fire emergency and their impacts on the evaluation of life safety aspects (ISO/TR 16738, 2009). This technical report addresses parameters related to life safety designs and assessments of building occupants’ conditions with respect to time. The parameters range from building design to occupant characteristics to disaster dynamics. The building parameters include floor layouts, warning systems, life safety management, emergency procedures, and so on. The occupant parameters include numbers, locations, characteristics, conditions, and so on. The assessment parameters focus primarily on occupants’ evacuations. They rely on two basic performance characteristics: (1) available safe-escape times (ASET), and (2) required safe-escape times (RSET). The report suggests a fire-safety engineering design guideline: ASET should be greater than RSET.

Fig. 1 illustrates how these processes occur over time, beginning with the time when alert systems first announce the emergency and continuing through the time when individuals can safely evacuate. Two types of emergencies are addressed in the figure: emergencies that can be predicted and emergencies that cannot be predicted. Tsunamis fall into the latter category. Thus, the prediction period has been added to the original diagram in Fig.

1. We assumed that fire was the cause of the emergency.

\[ t_{\text{pred}} : \] The interval that occurs between the moments when alarm systems announce an emergency will occur and when the emergency actually occurs.

\[ t_{\text{det}} : \] The interval that occurs between the initiation of the emergency and the moments when authorities, such as government officials, fire offices, among others, detect the occurrence.

\[ t_{\text{warn}} : \] The period during which authorities provide alarms or warnings to individuals.

\[ t_{\text{rec}} : \] The time individuals require to recognize that an emergency has occurred.

\[ t_{\text{res}} : \] The time individuals require to respond to the situation by evacuating to safe places or contacting others to ensure their safety.

\[ t_{\text{pre}} : \] The pre-travel activity time (PTAT) consists of the sum of \( t_{\text{rec}} \) and \( t_{\text{res}} \). It represents the interval that elapsed between the moments that individuals first heard warnings until the time they begin to evacuate.

\[ t_{\text{trav}} : \] The time individuals required to travel to safety.

\[ t_{\text{evac}} : \] The time required for evacuation consists of the sum of \( t_{\text{pre}} \) and \( t_{\text{trav}} \).

\[ t_{\text{marg}} : \] The time elapsed until the tenability limit is reached for evacuation completion.

With respect to the GEJE, the emergency combined earthquakes and tsunamis (see Table 1). The times for prediction, occurrence, and detection were the same: 14:46. The warning time occurred at 14:49. The tenability time occurred at 15:00 (or 15:25). Thus, \( t_{\text{evac}} \) ranged between 11 and 36 minutes.

3.2. Where people evacuate during emergencies

Kitao (1986) conducted a questionnaire survey with individuals who shopped at a Tokyo department store. The survey focused on factors related to evacuation behaviors in public spaces. Three hundred subjects were selected from shoppers in the department store. The number of male and female participants was equal. Participants varied between teenagers and adults in their 60s. The number of participants in each group was equal. The questions addressed the following behaviors that occur during emergencies: the provision of evacuation instructions during emergencies, knowledge of emergency exit locations, individuals’ abilities to evacuate safely, and other factors.

<table>
<thead>
<tr>
<th>Time</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:46</td>
<td>Emergency earthquake alert system</td>
</tr>
<tr>
<td></td>
<td>Earthquake bulletins broadcasted. The earthquake had a moment magnitude of 9. It continued for about 6 minutes.</td>
</tr>
<tr>
<td>14:49</td>
<td>Tsunami warnings were issued: “A big tsunami will hit at around 15:10.”</td>
</tr>
<tr>
<td>15:15</td>
<td>Aftershocks occurred.</td>
</tr>
<tr>
<td>15:00-15:25</td>
<td>An initial, relatively small, tsunami struck.</td>
</tr>
<tr>
<td>15:25-15:40</td>
<td>A much larger tsunami arrived.</td>
</tr>
</tbody>
</table>

Table 1: Event sequence for the GEJE (March 11, 2011)
Table 2 lists evacuation strategies, as well as the percentages of subjects who selected each strategy. The results revealed:

- Individuals’ intentions during emergencies were diverse. Differences were apparent between the sexes and between age groups.
- Half of all surveyed individuals stated they would follow authorities’ instructions. The other half stated they would select directions by themselves, and individuals who chose the fourth and fifth strategies tended to choose opposite directions. They expressed specific purposes for their choices of strategies.

The survey was conducted during a daily life situation. However, individuals’ real behaviors during emergencies may differ significantly. For example, during the experiment, individuals who decided not to follow instructions did not actually receive instructions or announcements. The instructions or announcements might also include the third category (see Appendix).

Failure to provide evacuation shelters can lead to tragedies. For example, a tragedy occurred at the Ookawa elementary school during the GEJE (Ookawa, 2011). The majority of students in the Ookawa elementary school were engulfed by the tsunami and died. This occurred despite the fact that the students had been informed of the large earthquake one hour prior to the tsunami’s impact. The school was located 5 km from the sea. As a result, they engaged in late evacuation because they did not expect the tsunami to strike the school. The school had never practiced evacuation drills. They failed to identify evacuation locations in the case of emergencies. When the earthquake occurred, all students had assembled on the ground. An hour elapsed before teachers decided on an evacuation location. During the time that teachers and students progressed towards that evacuation location, a police agent informed them that the tsunami was imminent and that their evacuation location was unsafe. The group decided to travel to a higher location but their efforts were too late.

4. Information transmission during evacuations

4.1. Communication model during emergencies

Human behavior depends on available evacuation times and the number of evacuees involved during emergencies. The provision of informational announcements during evacuations can affect human behavior. The messages were conveyed to the students by the school’s public address system.

Table 2: Responses to “In which direction would you evacuate?” (Kitao, 1986)

<table>
<thead>
<tr>
<th>Selected directions</th>
<th>All (300)</th>
<th>Man (150)</th>
<th>Woman (150)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Follow instructions from clerks or announcements</td>
<td>46.7</td>
<td>38.</td>
<td>54.7</td>
</tr>
<tr>
<td>2. Hide from smoke</td>
<td>26.3</td>
<td>30.7</td>
<td>22.0</td>
</tr>
<tr>
<td>3. Go to the nearest staircase or emergency exit</td>
<td>16.7</td>
<td>20.7</td>
<td>12.7</td>
</tr>
<tr>
<td>4. Follow other individuals’ movements</td>
<td>3.0</td>
<td>1.3</td>
<td>4.7</td>
</tr>
<tr>
<td>5. Go in the direction that has fewer people</td>
<td>3.0</td>
<td>2.7</td>
<td>3.3</td>
</tr>
<tr>
<td>6. Go to bright windows</td>
<td>2.3</td>
<td>2.7</td>
<td>2.0</td>
</tr>
<tr>
<td>7. Return to the path</td>
<td>1.7</td>
<td>2.7</td>
<td>0.7</td>
</tr>
<tr>
<td>8. Other</td>
<td>0.3</td>
<td>0.7</td>
<td>-</td>
</tr>
</tbody>
</table>
included in the announcements can exert important im-
   pacts on effective evacuation efforts:

- At the individual level, factors that influence individu-
   als’ behaviors are diverse. Selection of the appropriate
   strategy based on correct information is critical.
- At rescue headquarters, the first announcement may
   have been prepared in advance. Evacuation messages
   must change over time as additional data becomes
   available so that leaders can provide effective guidance
   during evacuations.

Weaver specifies that three levels are included in
   Shannon’s communication model (Claude, 1964):

Level A: How accurately can the symbols of communi-
   cation be transmitted from sender to receiver? (The technical problem.)
Level B: How precisely do the transmitted symbols con-
   vey the desired meaning? (The semantic prob-
   lem.)
Level C: How effectively does the received meaning af-
   fect conduct of receivers in the desired way? (The effectiveness problem.)

During emergencies, the warnings or evacuation guid-
   ance provided must be heard by individuals (level A). Once individu-
   als have recognized the dangers involved in the situation outlined in the announcement (level B), they
   must move to safe places (level C).

Fig. 2 illustrates the way that individuals internally
   process guidance information provided by authorities. Indi-
   viduals obtain data by experiencing the emergency as it un-
   folds around them: They hear authorities’ announce-
   ments or they exchange data related to the emergency
   with one another through communication (these actions
   are represented by solid black arrows in the figure). Once
   they receive data, individuals attempt to comprehend the
   data by comparing it with their own knowledge and/or ex-
   periences. Then, they plan their succeeding actions based
   on their comprehension (these actions are represented by
   dotted blue arrows in the figure). The dotted red arrow
   that appears in the figure corresponds with communica-
   tion that occurs at Level C. The authorities, as one com-
   ponent of the environment, serve as an information source. Messages sent to individuals consist of warnings related
   to predictable emergencies or guidance that provides di-
   rections for egress. Individuals choose their actions based
   on their own knowledge and experiences, as well as on
   their roles in the community. Places that they believe to
   be safe are selected as their destinations.

Noise can affect the transference of information dur-
   ing two stages that occur in the process that begins with
   the provision of a warning and ends with a choice of ac-
   tion. Noise can prevent individuals from selecting ap-
   propriate strategies that will help them achieve safe and
   quick evacuations. The first stage involves individuals’
   abilities to sense data in the environment. Some indi-
   viduals miss announcements or misunderstand messages.
   The second stage involves individuals’ choices of actions
   based on their personal databases comprised of data they
   have compiled with their senses. Scholars have noted that,
   during emergencies, individuals may misunderstand situ-
   ations and make faulty decisions based on their mental bi-
   ases. In Fig. 2, the Belief-Desire-Intention (BDI) model is
   used to represent individuals’ internal selection processes. Mental biases are represented by the filtering functions
   that operate from Sense data to the set of Belief, from the
   Belief to Desire, and the Desire to the set of Intention.

4.2. Evacuation simulations that address information

Evacuation guidance and human behavior play important
   roles in the development of models that illustrate the ways
   individuals process information during emergencies. Our
   agent-based evacuation simulation is comprised of agent,
   environment, and crowd simulations (Masaru, 2011).
• Agent and inter-agents: Human agents hear announcements provided by authorities, confirm the provided data with other agents in the area, and perform chosen actions. We adopted a BDI model to represent this process. Belief consists of the set of knowledge and information each agent possesses during every sense-reason-act cycle. Knowledge includes the layouts of buildings, locations of exits, and personal data, such as the number of agents who have families.

• Environment module: This module consists of data related to environments and emergencies. The environments consist of 3D CAD models of buildings. The emergency situations consist of locations in which fires occur, locations in which individuals are unable to hear announcements clearly, or related changes in those environments (e.g., corridors become obstructed by fires).

• Crowd simulation: The module simulates individuals’ dynamics based on physical differences that might arise from sex and age. People attempt to travel to their chosen destinations based on their intentions. Rescue responders travel to assigned places to guide individuals to safety. Rescue responders’ movements may act as obstacles to other evacuees’ movements.

5. Evacuation simulation that addresses information

5.1. Evacuation scenarios

Fig. 3 provides an illustration of a five-story building. It provides a snapshot of a simulation that represents 1,000 people (200 people on each floor) evacuating a five-story building. The building we chose was our university library; Fig. 4 illustrates the layout. The building contains six stairways: Two stairways run from the fifth floor to the first floor. Four stairways run between neighboring floors. The building has two exits: The front exit is situated on the second floor. An emergency exit is situated on the first floor. The front exit is 3.7 m wide. The emergency exit is 1.3 m wide.

Table 3 illustrates the three simulation scenarios. Two cases were simulated for each scenario (i.e., with and without emergency announcements). The announcements were modeled on the WTC emergency guidelines (see Appendix). The contents of the announcements were changed for each floor to smooth the flow of evacuation movement. Agents located on the first, third, and fifth floors were guided to egress by using the stairway. They were told to exit from the emergency exit. Agents located on the second and fourth floors were guided to exit from the front entrance (see Table 4). In the case in which no announcements were provided, all agents normally left from the front entrance because they were not informed of the existence of the emergency exit.

The differences among scenario 1 and scenarios 2 and 3 are based on the agent categories. Categories 1, 2, and 3 correspond to the instant-evacuation, evacuation-after-tasks, and the emergency-evacuation categories described in Section 2, respectively. In scenario 1, all agents were drawn from the instant-evacuation category. They initiated their own evacuation at the beginning of the simulation. In scenarios 2 and 3, agents were drawn from all three categories. The ratios were set to 57%, 31%, and 12%, respectively, based on GEJE reports (Japan Cabinet, 2012). Agents drawn from the evacuation-after-tasks and emergency-evacuation categories evacuated five minutes after the beginning of the simulation, or once they received evacuation guidance. The differences that occurred...
between scenarios 2 and 3 depended on whether communication loss occurred. According to the GEJE reports, 82% of the individuals involved heard the emergency announcements provided by authorities. Further, 82% of the individuals who heard the announcements understood the guidance contents clearly. The remaining individuals failed to understand the messages. In addition, 18% of individuals who missed the emergency and 18% of individuals who heard the announcement and failed to understand the situation did not evacuate immediately, even if they were instant-evacuation agents. Approximately, 33% of the individuals who failed to hear or did not understand the emergency announcements acted based on their own BDI models (see Fig. 2).

In the BDI model, the agent category is determined by the degree of awareness of danger.

- **Belief** ($B_t$): $B_t = \text{belief}(S_t, B_{t-1})$
  When a person hears evacuation instructions, he/she considers his/her safety more important than other jobs. Some agents who do not believe they are in danger might change their beliefs when they hear evacuation instructions. The awareness of danger and its relationship with beliefs will change based on the agent’s mindset.

- **Desire** ($D_t$): $D_t = \text{option}(B_t, I_{t-1})$
  Changes in beliefs will affect desires. Most individuals are performing tasks. Thus, they may want to finish their tasks normally. At emergencies, some may behave differently.

- **Intention** ($I_t$): $I_t = \text{filter}(B_t, D_t, I_{t-1})$
  Agents filter one particular action from a number of suitable actions to achieve their personal desires. Agents develop their personal preferences based on their personalities and social norms. An agent might intend to evacuate or he/she might continue his/her work.

$S_t$ is a set of sensor data that an agent receives at time $t$. $B_t$, $D_t$, and $I_t$ represent the status of beliefs, desires and intentions, respectively. $B_t$ consists of rules of action, knowledge, and states. Differences in agent types are implemented by the use of different $\text{belief}$, $\text{option}$, and $\text{filter}$ functions.

5.2. Results of the simulations

Fig. 5 illustrates the simulation results for scenario 1. The average values of four simulations are plotted with standard deviations. The left graph lists the number of agents that left the building from the front exit. The middle graph lists the number of agents who left the building from the emergency exit. The right graph lists the total number of agents who left the building from any exit. All agents left from the front exit when guidance was not provided. However, agents left from different exits when guidance was provided. After ten minutes elapsed following initiation of the simulation, over 300 people had left the building after guidance was provided. In contrast, fewer agents left when guidance was not provided. These results demonstrate that the provision of announcements helped more agents evacuate the building.

Times for last agents’ exits from the building were almost similar, regardless of whether guidance was provided. Fig. 6 provides snapshots of the simulated exits from the front entrance when an announcement was not provided, as well as snapshots of simulated exits from the emergency exit when an announcement was provided. The width of the passage that led to the emergency exit was about one-third the width of the passage that led to the front entrance. Congestion that occurred at the emergency exit caused almost similar total evacuation times.

Table 5 provides a comparison of the simulation results for scenarios 1, 2, and 3. In the cases of evacuation without provided guidance that occurred in scenarios 2 and 3, the number of agents who left from the front entrance was less than 500. This occurred because some agents from the evacuation-after-tasks and emergency-evacuation categories did not believe they were in danger. Hence, they did not evacuate. In the version of scenario 3 in which guidance was provided, the number of agents who left from the front entrance was higher than the numbers tabulated in the other cases. This occurred because some agents from the emergency-evacuation category who failed to hear the announcements made their exit decisions based on their personal BDI models. As a result, more agents left the building from the front entrance, rather than from the emergency exit. Therefore, evacuation times were longer for this case, rather than for the other cases.

### Table 3: Simulation scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Announcement</th>
<th>Agent category*</th>
<th>Data loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>1+2+3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1+2+3</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td>1+2+3</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1+2+3</td>
<td>33%</td>
</tr>
</tbody>
</table>

* 1, 2, 3 correspond to instant-evacuation, evacuation-after-tasks, emergency-evacuation categories. The ratios are 57%, 31%, and 12%, respectively.
Table 4: Exit guidance provided during phased evacuation (contents of announcements differed for each floor)

<table>
<thead>
<tr>
<th>floor</th>
<th>exit routes (stairs)</th>
<th>with guidance (phased evacuation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5F</td>
<td>front stair 1, 2</td>
<td>emergency stair 1, 2</td>
</tr>
<tr>
<td>4F</td>
<td>front stair 1, 2, 6</td>
<td>front stair 1, 2, 6</td>
</tr>
<tr>
<td>3F</td>
<td>front stair 1, 2, 3</td>
<td>emergency stair 1, 2, 3</td>
</tr>
<tr>
<td>2F</td>
<td>front exit</td>
<td>front exit, stair 1, 4, 5</td>
</tr>
<tr>
<td>1F</td>
<td>front stair 1, 4, 5</td>
<td>emergency exit</td>
</tr>
</tbody>
</table>

(a) Agents’ egress from front exit
(b) Agents’ egress from emergency exit
(c) Agents egress from any exit

Figure 5: Results of four simulations for scenario 1. (a) (b) (c) Number of agents egresses from front entrance, emergency exit, and both exits, respectively.

6. Summary

Many organizations conduct preparations and provide training for emergencies to protect against future disasters. The information provided during trainings and the processes described in evacuation manuals are designed to move individuals quickly and smoothly to safe places, as well as to ensure effective conduct of rescue operations. Reports related to disasters, such as the September 11 attacks and the GEJE, as well as the ensuing tsunami, have provided important lessons related to human behavior during emergency situations (Averill, 2005, Japan Cabinet, 2012). One key lesson demonstrates that humans behave differently during emergencies and that the provision of evacuation announcements can significantly influence human behavior during emergencies. Two different stages occur during the transfer of messages from authorities to individuals. The first stage involves a technical and semantic problem derived from Shannon’s communication model. Data loss can occur because of noise interference. As a result, people fail to receive messages that convey authorities’ guidance. The second stage involves the effectiveness problem. Some individuals will evacuate immediately. However, other individuals will not evacuate despite the fact that authorities have provided evacuation announcements.

We believe that authorities’ provision of announcements represents an effective way to encourage individuals to cease their tasks and evacuate to safe places. In this paper, we proposed an information transfer model that represents ways humans react when they hear emergency information. In our evacuation simulation system, broadcasted announcements affected agents’ behaviors. We represented agents’ mental status with a BDI model. Their mental status led to divergent behaviors. The BDI model presents three human categories of reactions based on GEJE reports: instant evacuation, evacuation-after-tasks, and emergency evacuation.

Our simulations revealed the following results:

1. Manuals compiled for use during emergencies specify the provision of announcements to guide agents based on particular situations. These phased evacuations were described in the WTC emergency guidelines to increase evacuation efficiency. In this study, phased evacuations were simulated and the effects and

Table 5: Simulation results for Scenarios 1, 2, and 3

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Front Entrance</th>
<th>Emergency Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>without guidance</td>
<td>with guidance</td>
</tr>
<tr>
<td>scenario 1</td>
<td>500 ± 0</td>
<td>10.65 ± 0.05</td>
</tr>
<tr>
<td>scenario 2</td>
<td>444 ± 5</td>
<td>12.47 ± 0.17</td>
</tr>
<tr>
<td>scenario 3</td>
<td>443 ± 5</td>
<td>12.70 ± 0.14</td>
</tr>
</tbody>
</table>

* 1, 2, 3 correspond to instant-evacuation, evacuation-after-tasks, emergency-evacuation categories. The ratios are 57%, 31%, and 12%, respectively.
problems in the contents of these types of guidance were indicated.
2. Scenario 1, in which all occupants were classified in the instant-evacuation category, demonstrated the shortest evacuation time. Noise interference that resulted in data loss during authorities' provision of guidance, as well as a variety of human behaviors, increased agents' egress time during evacuation.

These results reveal that our information transfer model can provide useful information for the development of building evacuation plans and for the analysis of their effectiveness.

7. Appendix

The following examples consist of texts prepared for a variety of emergency scenarios that were included in the World Trade Center Emergency Guidelines (Averill, 2005, p. 35). According to the guidelines, information and instructions to be broadcasted to buildings' occupants could be modified to suit particular emergencies.

Example 1: Prior to all emergency announcements, the following pre-announcement was made: Your attention please, your attention please. An important public address announcement will be made in the main corridor of your floor in a few moments.

Example 2: Evacuation for any reason, including fire or smoke, would have generated the following announcement, enabling a phased evacuation: Your attention please. We are experiencing a smoke condition in the vicinity of your floor. Building personnel have been dispatched to the scene and the situation is being addressed. However, for precautionary reasons, we are conducting an orderly evacuation of floors. Please wait until we announce your floor number over the public address system. Then, follow the instructions of your fire safety team. We will continue to keep you advised. We apologize for the inconvenience and we thank you for your cooperation.

Example 3: The standard evacuation announcement for a particular floor was, Your attention please. It is now time for your floor to be evacuated. In accordance with the directions from your fire safety team, please take the exit stairs nearest to your location. We remind you that communications, emergency lighting, and other essential services are in service. We will continue to keep you advised. We apologize for the inconvenience and we thank you for your cooperation.

References


Citation