Evaluation of a Support System for Large Area Tourist Evacuation Guidance: Kyoto Simulation Results

Seiki Kinugasa, Tomoko Izumi and Yoshio Nakatani

Abstract Most studies on providing evacuation guidance have targeted residents, with little consideration for evacuation guidance for visitors to the area, such as tourists and businesspeople. Accordingly, this study targets the development of a system that supports the safe and efficient evacuation of tourists from disaster areas to specific safe destinations. The system models the evacuation behavior of tourists and then simulates an evacuation process in which a specific evacuation guidance method is utilized. A major characteristic of tourists in disasters is that they tend to converge on the limited number of railway stations, which may result in severe crowding and panic. The system therefore makes it possible to compare and evaluate the effectiveness of various evacuation guidance methods. The effectiveness of the system was tested by simulation of evacuation processes that utilize a phased evacuation guidance method that is to be introduced in Kyoto, the most popular tourist destination city in Japan.

Keywords Shortest path · Evacuation · Simulation · Visualisation

S. Kinugasa (✉) · T. Izumi · Y. Nakatani
The Graduate School of Science and Engineering, Ritsumeikan University, Kusatsu city, Shiga 525-8577, Japan
e-mail: cc006064@ed.ritsumei.ac.jp

T. Izumi
e-mail: izumi-t@is.ritsumei.ac.jp

Y. Nakatani
e-mail: nakatani@is.ritsumei.ac.jp

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1 Introduction

In Japan, which has recently suffered the unparalleled Tohoku earthquake, there is a possibility that further large earthquakes, such as Tonankai and Nankai Earthquakes or a major earthquake in the Tokyo Metropolitan Area, will occur in the near future. Therefore, both the central Japanese and local governments have been taking various countermeasures, and in the meantime the government has positioned tourism as a major economic growth area [1]. The Tourism Nation Promotion Basic Law came into effect in 2007, and the number of tourists has subsequently been increasing. Most countermeasures against disasters, however, target residents and rarely target tourists. These countermeasures are usually obvious because, no matter how famous the region is as a tourist destination, the number of residents is far higher than tourists. However, the countermeasures aimed at tourists are actually extremely important for protecting the livelihood of many residents. Tourists may decrease if there is a risk of suffering severe damage from disasters. Supporting tourists in ways such as protecting them from damage caused by disasters, and providing safe and quick evacuation, emphasizes the importance of tourists to the rest of the world. Thus it is very important that appropriate evacuation guidance and design guidelines are well prepared beforehand.

Devising evacuation guidance for tourists, however, is much more difficult than the usual guidance for residents which is considered only on a theoretical basis. Tourist behavior differs from residents, because tourists need to conduct long-distance evacuation in a large-scale area. Large-scale evacuation experiments are impractical, with computer simulation appearing to be the most effective.

With the aim of solving these problems, the purpose of this study is to provide administrative staff with an environment in which they can plan and verify safety guidance by computer, for quick guidance of tourists to safe destinations in a broad range of areas.

2 Existing Research

Although there are many systems for simulating evacuation guidance via computer, systems that model behavior for guiding tourists are very few. In most cases, the behavior of evacuees is simply implemented as the fluid model, and recently systems that consider interaction between evacuees were developed. Recently, RoboCup Rescue simulation has gained attention as a large-scale multi-agent system [2], but such simulators cannot verify or compare evacuation guidance for tourists in a large-scale area.

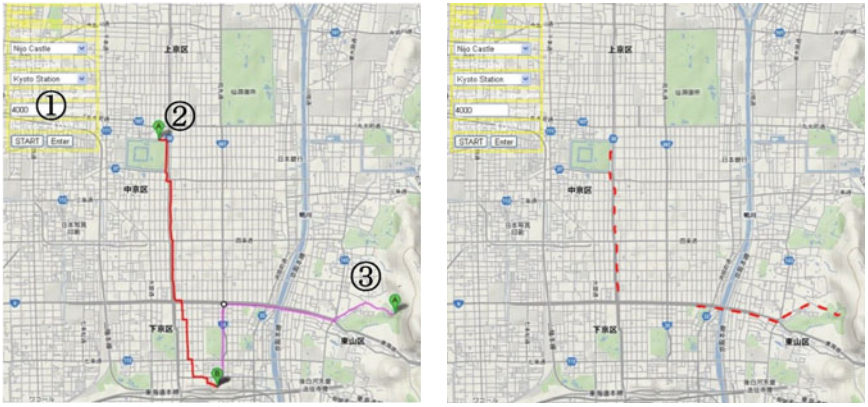
Few systems have been developed to support evacuation guidance for tourists. Among them, one example developed by Kyoto University in Japan involves an instructor who conducts evacuations for evacuees via mobile phones [3]. Locations of evacuees are constantly supervised based on location data provided by Global Positioning System (GPS) and are replicated in a virtual city called FreeWalk, which provides a bird's-eye view of the area. The instructor constantly observes the behavior of evacuees in the FreeWalk virtual world while providing them with instructions via mobile phones. Another system, developed by Wakayama University in Japan, enables evacuees to send disaster information and receive evacuation guidance via disaster information stations installed in a city [4]. A number of wireless devices therefore need to be installed throughout the area, and Bluetooth is used for communication between the users' mobile phones and wireless devices.

The evacuation guidance method proposed by Nakatani et al. of Ritsumeikan University, Japan involves evacuees being guided to temporary tourist shelters designated near sightseeing spots in a phased manner, in order to prevent concentration at any one time in the central part of a city [5]. It features "staging posts" as temporary refuges for tourists on the way to their destination (e.g. railway stations). The staging posts function as a buffer zone to prevent tourists from rushing into railway stations in the central parts of cities and thereby enabling fast evacuation of tourists from dangerous areas to safer areas, and reducing the fatigue caused by evacuation on foot. Cooperators in disaster areas, such as souvenir shop staff and tourist agents, are requested to send disaster information to the emergency management center. The emergency management center then determines and changes evacuation instructions based on this information before sending the instructions to the cooperators. The cooperators then guide evacuees to the nearest tourist shelter according to the instructions they receive. The cooperators, during the guidance, send their disaster information to the center at any time. This evacuation method is more practical than other methods because there is no requirement that all evacuees have a cellular phone equipped with GPS.

3 System Construction

The purpose of the proposed system is to compare and verify various evacuation guidance methods suggested by public authorities, and to support the development of effective evacuation guidance. The functions of this system will:

- Visually define evacuee behavior over time on a map.
- Simulate various evacuation methods for tourists and change the evacuation route depending on the situation.
- Show quantitative results and the effects on tourists of various primary factors (width of the road, traffic, etc.)
- Consider factors that keep evacuees in places of refuge on the way to their destination, such as using the staging posts.



(a) (b)

Fig. 1 System screen. **a** During input of evacuation guidance. **b** During the simulation

3.1 System Screen Configuration

The images shown in Fig. 1 display use of the system during input of evacuation guidance (Fig. 1a). Information about evacuation guidance is input in ①, with checking of the route and other information performed in ②. The details of this information are shown in Table 1. This input determines which shelter evacuees should go to, and via which route, for each destination, and is required for each point of origin. The thick line in Fig. 1a② shows the route during input of guidance (Nijojou to Kyoto Station). The thin line in Fig. 1a③ shows the route with input completed (Kiyomizu Temple to Kyoto Station). Fig. 1a shows the case of Table 1.

Figure 1b shows the system screen after the start of the simulation. The thick line shows the behavior of evacuees following a guide in line. The crowd appears as a dotted line because many evacuees are separated and are individually evacuated in small groups. Each small group has one guide.

Table 1 Contents of input information

Evacuation info.	Input details	Input ex.
Origin	"Address" or "longitude and latitude"	Nijo-jou
Staging post	"Address" or "longitude and latitude" or nothing	(None)
Waiting time	Waiting time at the staging post	0:00
Destination	"Address" or "longitude and latitude"	Kyoto Sta.
Evacuation route	Dragging the route line on the map	Shortest Route
Number of evacuees	Number of evacuees at the origin	4000

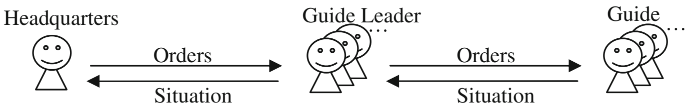


Fig. 2 Chain of command

3.2 System Process

This section outlines the process during simulation. This system, after the start of the simulation, designates one "Headquarters", multiple "Guide Leaders" and "Guides" from the viewpoint of the usual chain of command at the time of disaster (Fig. 2). The evacuation guidance inputted before the start of simulation is analyzed at the "Headquarters" and sent to each "Guide Leader" and "Guide". Each origin point has one "Guide Leader". "Guides" receive the orders from the "Guide Leader", and guide evacuees.

Figure 3 is a representation of the system flow after the "Guide" starts evacuation. "Move Evacuees" indicates the transition of evacuees from each step to the next, where a step is the minimum unit from the point of origin to the destination. Each step includes the next step's position, distance, and width of the road. The movement process is calculated based on this information, and transports evacuees in each step from the last step's position to the next step's position. This movement results in a line being drawn from the last step to the next step, thus depicting how the evacuees move in a bold line. The drawing speed of the crowd is proportional to walking speed.

In cases of changes in the width of the road or the merging of two evacuee groups, the density of the crowd and the walking speed change. Fruin [6] discovered that 4 persons per 1 m^2 leads to a sharp decrease in the walking speed. In this system the walking speed is calculated using this information, with equation being based upon it.

$$V(\rho) = 1.1\rho^{-0.7954} \tag{1}$$

ρ: crowd density (person/m^2)
v: walking speed (m/s)

4 System Evaluation

The effectiveness of the system was examined using Japan's most popular tourist destination city, Kyoto. The strong possibility also exists that an earthquake will occur in Kyoto [7]. As the phased evacuation guidance method was proposed by Nakatani for use in the tourist evacuation guidance field in Kyoto, we then examined the method by using it in our system.

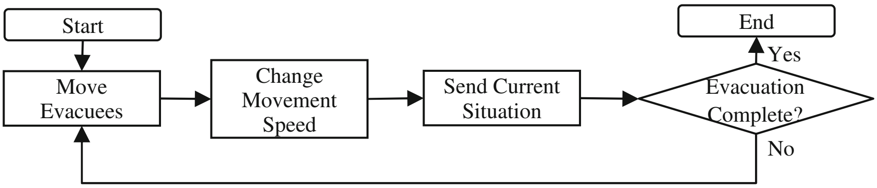


Fig. 3 Flowchart after start of the simulation

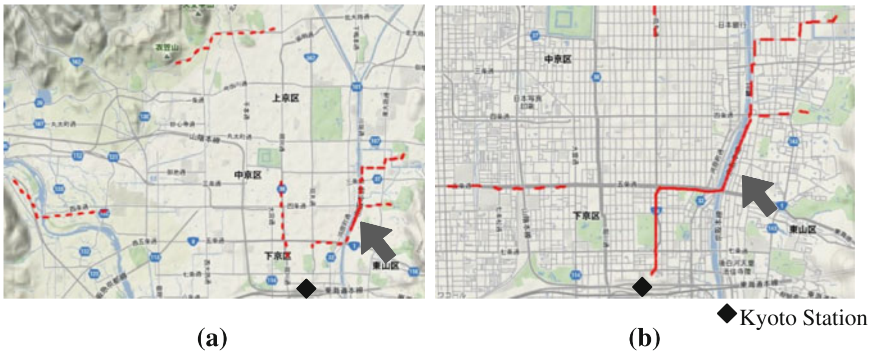


Fig. 4 System screen. **a** Screen after 100 min. **b** Screen after 142 min

Figure 4a shows the situation 100 min after the start of the simulation, and Fig. 4b shows the situation after 142 min. Most tourists are likely to head towards Kyoto Station to return to their homes in case the railway service has resumed after an earthquake. The arrow in Fig. 4a shows that each evacuee group merges and crowds together. The arrow in Fig. 4b after 42 min shows a long line of evacuees and dangerous traffic combined with severe vehicle congestion. This system therefore clarifies problems or danger in evacuation guidance methods, including which places will become dangerous at what times and how to improve the situation.

The results were evaluated by two persons from the Kyoto City Fire Department with regard to the effectiveness of the system, with the result being that they considered it effective.

5 Conclusion

This paper has demonstrated the necessity for the proposed system and presented the process and evaluation of the system. In the future we would like to develop a detailed behavioral model that includes merges, splits, stops and slowing of an evacuee line with psychological factors taken into consideration. We then hope to develop and evaluate the system with the help of an expert. We are first considering applying the system in Kyoto City, and the system is applicable to other tourist destination cities,. Finally, our heartfelt appreciation goes to Kyoto City Fire Department officials.

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