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

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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 to be introduced in Kyoto, the most popular tourist destination city in Japan.

Index Terms—evacuation simulation, tourist, evacuation guidance

I. 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. Despite this, 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, although any major future earthquakes will result in a decrease of tourists in the short term.

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Most countermeasures against disasters target residents and rarely target non-residents, such as tourists and commuters. When regional disaster prevention plans were examined at the prefectural level in Japan, 11 out of 30 prefectures were identified as including tourists, but in very little detail.

In Japan, as a disaster-prone country, disaster countermeasures aimed at tourists not only need to protect visitors, but also the residents of tourist areas. Tourists may decrease if there is a risk of suffering severe damage from disasters. The time needed for recovery of tourist industries will take a far longer period than most people may assume. Countermeasures against disasters in place for tourists can therefore protect not only tourists, but also the local tourism industry and indeed the tourism reputation of Japan.

The possibility of a secondary disaster occurring depends not only on the scale of the original disaster or the countermeasures in place, but also the state of evacuation procedures. Plans for regional disaster countermeasures need to include accurate guidance of evacuees to their destinations in addition to the material aspects of disaster prevention facilities and equipment. 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 guidance for residents, which does not need to consider long distance evacuation in a large-scale area. Evacuation experiments are impractical because of the large numbers of participants and areas, and thus computer simulation appears to be the most effective method.

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.

II. Evacuation Guidance for Tourists

This section outlines some problems in existing evacuation guidance, and introduces phased evacuation guidance, a new method of evacuation guidance.

A. Existing evacuation guidance

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 [2]. Locations of evacuees are constantly supervised based on location data provided by GPS (Global Positioning System) and are

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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 [3]. 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.

B. Phased Evacuation Guidance

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 [4]. It features "staging posts" as temporary refuges of tourists on the way to their destination such as railway stations.

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 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. The specific effectiveness of this method, however, has not yet been verified.

III. System Construction

A. Approach

The administrative staff needs to be supported with information systems, as it is difficult for visitors to evacuate by themselves without accurate evacuation guidance because they are strangers in the area. The design of an appropriate evacuation guidance method thus requires understanding of the evacuation situations that can actually occur when specific guidance methods are adopted. Because large-scale evacuation experiments are impractical, our approach is to model tourist behavior tendencies by computer and simulate their behavior to find the most effective evacuation guidance method.

Simulating evacuation behavior has been investigated in various fields. However, no simulator has been devised that can be used to verify the effectiveness of evacuation guidance methods for tourists. Recently, RoboCup Rescue simulation systems as large-scale multi-agent systems have been challenged [5]. Most RoboCup Rescue systems cannot simulate evacuation behavior of tourists to target residents and rescue methods in cities that are tourist areas. We therefore developed a new system that simulates the evacuation behavior of tourists in a large area using a specific method and then quantitatively evaluated the results.

B. System Screen Configuration

This section outlines the specifications of this system in reference to Figure 1.

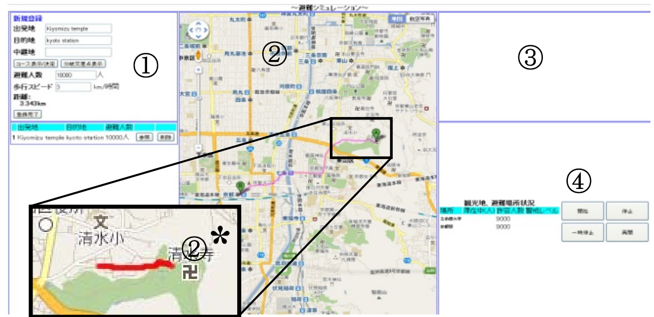

Fig.1: System screen

① Evacuation guidance methods input space:
The evacuation guidance method is entered here. The details of this information are shown in Table 1. The "origin" is the start point of the evacuation and the "destination" is the end point. The "staging post" is an intermediate point between the origin and the destination. The "waiting time" is the time spent waiting at the staging post. The "staging post" is entered many times, and the "waiting time" has to be entered with the staging post. The "evacuation route" is changed by dragging the route line on the map ②. The "number of evacuees" equals the number of evacuees at the origin. These are considered one data set and can be entered many times. The evacuation guidance method is then determined using this input. In brief, this process decides which shelter evacuees should go to, and via which route, for each destination.

TABLE 1
Contents of Input Information

Evacuation info.	Input details
Origin	"Address" or "longitude and latitude"
Staging post	"Address" or "longitude and latitude" or nothing
Waiting time	Waiting time at the staging post
Destination	"Address" or "longitude and latitude"
Evacuation route	Dragging the route line on the map
Number of evacuees	Number of evacuees at the origin

② Simulation display space:
This space shows the evacuation route and evacuation behavior graphically. In Figure 1, ② shows the screen during entering guidance methods on ①, and ②* shows the enlarged screen of ② after the start of the simulation. This figure shows the transition of evacuees from Kiyomizu Temple to Kyoto Station. Evacuees in transit are shown as a thick line. One minute in real time is one second in the simulation.

③ Situation display space:
This space shows the evacuation situation, including the number of evacuees in the area.

④ Operation button:
This space is used to start, stop, pause, and resume the simulation.

C. System process

The following flowchart represents the process after the simulation starts (Figure 2).

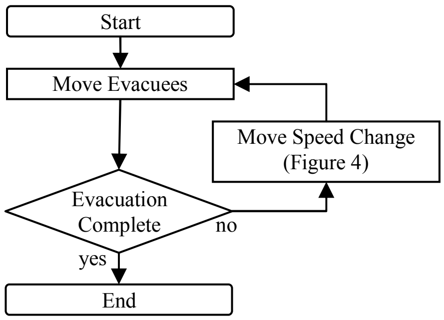

Fig.2: Flowchart of process after start of simulation

"Move Evacuees" represents the transition of evacuees from each step to the next. A step is the minimum unit from the origin to the destination. Each step includes the next step position, distance, and width of the road. The move is calculated based on this information and transports evacuees in each step from the last step position to the next step position. This move results in a line being drawn from the last step to the next step, thus depicting how the evacuees move in a bold line.

"Evacuation Complete" shows that the evacuees in the last step have reached their destination.

The system includes conditions that change their Speed of Movement, with that speed depending on density of the crowd. The crowd density shows the number of persons per 1㎡, and is calculated based on the width, distance and number of evacuees in a step area. A high crowd density results in a decrease in the walking speed and thus a delay in the evacuation. Below are the speed equation (1) and a flowchart of the process after the start of the simulation (Figure 3).

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

ρ：crowd density (person/㎡)
v：walking speed (meter/second)

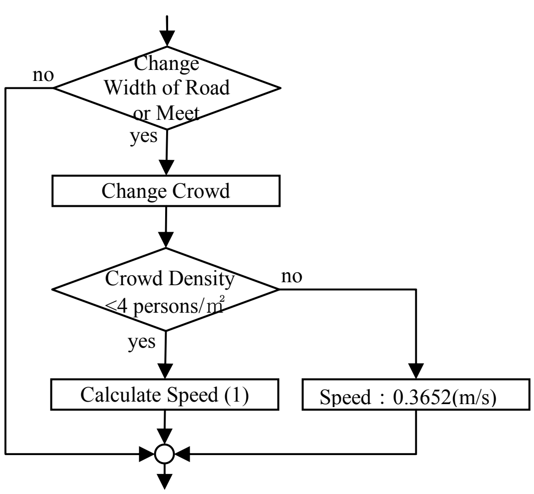

Fig. 3: Flowchart of change in speed

Togawa revealed the relationship between the density and the walking speed. Fruin [6] discovered that 4 persons per 1㎡ leads to a sharp decrease in the walking speed. In this system the walking speed is calculated using this information, with Equation （1） being based upon it.

In the system the walking speed is changed when the width of the road widens or when two evacuee groups meet and merge （Figure 3）. A narrow road results in an increase in the crowd density. The size of the step then changes, but the number of persons in each step does not. Evacuation groups merging also increases the density. The number of persons in a step changes, but the size of the step does not. If the density is lower than 4 （persons/㎡） the walking speed depends on Equation （1）, but if the density is higher than 4, the walking speed is 0.3652 （meter/second）, and the density remains at 4. The length of crowd then increases, revealing that the crowd extends backward when it has passed the limit.

The current version of the system does not completely take into consideration changes in the width of the road and the merging of two groups. When two groups merge, the walking speed does not slow down. The length of a group also does not change even when the width of the road changes. These deficiencies are currently being improved upon, thus obtaining more realistic results.

IV. System Evaluation

The effectiveness of the system was examined using Japan's most popular tourist destination city, Kyoto. As the phased evacuation guidance method was proposed by Nakatani for use in the tourist evacuation guidance field in Kyoto, we examined the method by using it in our system and obtained an evaluation of the results from experts.

The system does not currently include all features in full, but is at a level where it can be evaluated.

A. Kyoto

Kyoto is world-famous tourist destination city and was visited by 50,210,000 tourists in 2008. The number of tourists during the autumn foliage season in November was the largest in the year, numbering 6,590,000 tourists. The following list outlines the features of Kyoto's tourists. These features are considered to imply a tendency for Kyoto to be crowded with many evacuees in a disaster situation and to cause panic at stations, because most tourists are from the Kinki region, including Osaka, Hyogo, Nara and Shiga Prefectures, and visit by train. A prompt decrease in travel and tourism after a disaster is also expected for many elderly female and independent visitors.

- Many female tourists: 63.5% of tourists are female
- Many elderly tourists: 63.5% are over age 40
- Many tourists from the Kinki region:
  - Kinki region: 61.2%（from within Kyoto Prefecture: 10.5%）
  - Kanto region, including Tokyo: 14.0%
- Many independent tourists: 90.3% not with tour groups
- Many day tourists: 73.6% are day trippers
- Many repeaters: 54.5% of tourists have visited more than 10 times（24.5% said 5-9 times.）
- Many railway users: 61.8% visit by train

The possibility also exists that an earthquake will occur in Kyoto. According to a report from the committee of the Headquarters for Earthquake Research Promotion of the Japanese government, the probability of ground motion equal to or larger than a seismic intensity of 6 Lower occurring within 30 years in Kyoto City is more than 3% [7]. This probability is a high level even in earthquake-prone Japan. The probabilities of Tonankai and Nankai Earthquakes occurring are 60% and 55%, respectively, which are very high when compared to the probabilities of other earthquakes. It is predicted that such an earthquake will cause a ground motion of a seismic intensity of 6 Lower in Kyoto.

B. Simulation Conditions

Evacuation guides, when large-scale disasters occur, have to guide evacuees to safe evacuation areas chosen as temporary shelters in Kyoto City. After resumption of transportation including train services, many evacuees in some temporary shelters will simultaneously head for safe destinations including Kyoto Station because they hope to return to their homes quickly. A safe and efficient guidance method therefore is needed between temporary shelters and the destination.

This simulation verifies the evacuation situation after temporary evacuation is complete and train services resume. The situation implies that the evacuees from each temporary shelter go through a staging post to the specific destination. When aiming for early arrival, directly going to the destination, without going through the staging posts, is of course more effective. However, long-distance walking becomes a burden for elderly female evacuees, and tends to cause crowding of tourists at the destination. It is therefore required to verify how the staging posts should be used for the implementation of appropriate and safe evacuation guidance at the time of disaster. We verify the evacuation guidance in cases in which the number of staging posts is 0, 1 and 2, and compare those evacuation situations.

This simulation assumes the environment of Table 2. A Tonankai or Nankai Earthquake, which have the highest probability of occurrence, is envisioned to occur around noon in November when the number of tourists is the largest. This situation will require long-distance walking and cause confusion in the crowd.

TABLE 2
ASSUMED ENVIRONMENT OF SIMULATION

Purpose of evacuation guidance	Guidance to stations for tourists going home
Targeted city	Kyoto
Time of year	Noon, weekend, November
Assumed earthquake	Tonankai / Nankai Earthquake
Seismic intensity	Seismic intensity 5 Upper to 6 Lower
Train service situation	JR Line including Kyoto Station is resumed after 6 hours
Evacuation guidance method	Phased evacuation guidance

The specific temporary shelter, staging post, destination, number of evacuees, and evacuation route in this simulation are explained below. Figure 7 shows these specific positions. Table 3 shows which temporary shelter to go to via which staging post for the destination, and letters a-k in Table 3 correspond to those on Figure 7. When there are zero staging posts, the guide of the *temporary shelter* would directly go to destination "S" via the shortest route （Condition A）. When there is 1 staging post, the guide would go to *Staging Post 1* via the shortest route and, after arriving, take a 60-minute break and then go to the destination（Condition B）. When there are 2 staging posts, the guide would go through *Staging Post 1* and *Staging Post 2* like in Condition B, and then go to the destination via the shortest route （Condition C）. Locations "a", "c", "e", "j", and "k" of the temporary shelters are the nearest to each tourist site. *Number of evacuees* in the temporary shelters indicates when tourists, in the ten most popular tourist sites in Kyoto, are evacuated to the nearest shelter. The number of tourists at each site was calculated based on the number of visitors per hour. *Staging Posts 1* and *2* denote safe evacuation areas chosen as temporary shelters in Kyoto City and are near the route between each temporary shelter and the specific destination. *Destination* "S" was envisioned to be JR Kyoto Station. Other stations also were considered, but the effectiveness of phased evacuation guidance was considered to be obvious for Kyoto Station, as it is surrounded with staging posts. *Temporary shelter* "e" does not go through the staging posts as the distance between the shelter and the destination is short, and "j" does not go through Staging Post 2, as the distance from "i" to "S" is short and safe evacuation areas are not nearby.

TABLE 3
GOING THROUGH STAGING POSTS

Temporary shelter（number of evacuees）	▶	Staging post 1	▶	Staging post 2	▶	Destination
a （9,500）		b		d		S
c （8,400）		e		f		
e （4,000）						
j （20,300）		i				
k （8,500）		h		g		

V. RESULT

A. Result of the simulation

Tables 4, 5 and 6 each display the elapsed time from the start of guiding to the next position in the cases of A, B, and C. For example, in the case of Table 6, the guide reaches Staging Post 1 after 80 minutes and takes a 60-minute break there, then moves to Staging Post 2 in 69 minutes and takes a 60-minute break again, and finally reaches the destination in 25 minutes.

Figures 4 and 5 show the evacuation behavior displayed in ② of Figure 1, 95 minutes after start of the simulation. This simulation showed the occurrence of a long line from the origin to the destination in all results. Moreover, in the result of Condition A, the intersection in front of "j" has a tendency to be crowded with many evacuees in the dotted line in Figure 4. In Condition B, crowded space did not occur as shown in Figure 5, and also did not occur in Condition C. Figure 6 compares in the form of a graph Conditions A, B, and C. This shows the change in the number of evacuees reaching "S" at ten minutes intervals. The horizontal axis shows the elapsed time from the evacuation start. Evacuees begin to reach "S" 76 minutes after the start of the evacuation, and finish after 245 minutes in Condition A, 314 minutes in Condition B and 375 minutes in Condition C.

TABLE 4
RESULT OF CONDITION A

Minutes

Temporary shelter	- - - - - - - - →	Destination
a	167	S
c	148	
e	76	
j	73	
k	121	

TABLE 5
RESULT OF CONDITION B

Minutes

Temporary shelter	- →	Staging post 1	- - - - →	Destination
a	80	b	90	S
c	85	e	76	
e	76			
j	46	i	38	
k	40	h	88	

TABLE 6
RESULT OF CONDITION C

Minutes

Temporary shelter	- - →	Staging post 1	- - →	Staging post 2	- - →	Destination
a	80	b	69	d	25	S
c	85	e	55	f	18	
e	76					
j	46	i	38			
k	40	h	64	g	14	

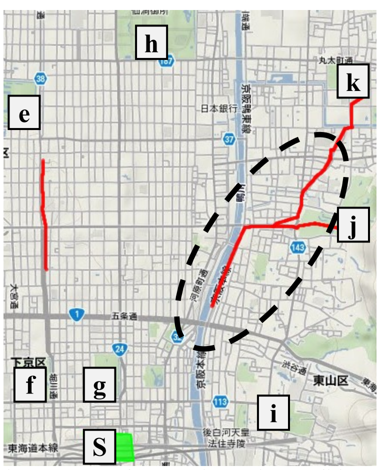

Fig.4: Screen after 95 minutes in Condition A

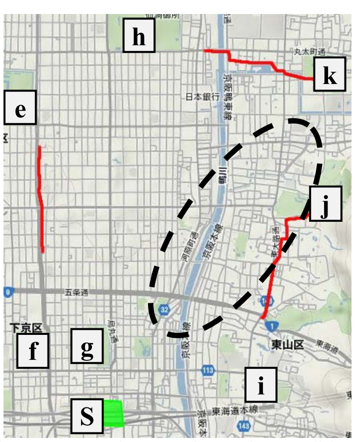

Fig.5: Screen after 95 minutes in Condition B

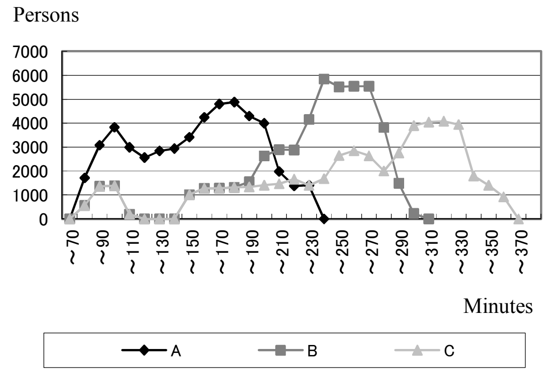

Fig.6: Change in the number of evacuees reaching "S"

B. *Consideration*

The results of the simulation will now be discussed.

- Condition C takes the shortest time on foot. The elapsed times of Conditions A, B and C are 167, 90 and 85 minutes respectively. In Kyoto, in which most tourists are middle-aged and older women, duration is very important.
- The lines of evacuees did not take the same route at the same time in Conditions B and C. Aiming at different staging posts thus can avoid the occurrence of dangerous secondary disasters.
- The most stable change in these 3 conditions occurs in C （Figure 6）. The volume of passengers carried by train is unchanged, and stable change is therefore required for avoiding secondary disasters. The most unstable change occurs in B. Having staging posts does not depend on stable change, but gives respite from moving on foot. A guidance method that considers both of these is required.

From the above, the effectiveness of phased evacuation guidance can be seen in the following aspects:

- Establishing staging posts avoids a long crowd of evacuees, and rest times are provided.
- Stable evacuation guidance is enabled in some staging posts and at the last destination.
- The risk of secondary disaster due to crowding of evacuees is mitigated by proper selection of staging posts.

C. *Evaluation by Experts*

The results were evaluated by two persons from Kyoto City Fire Department with regard to the effectiveness of the system, with the result being that they considered it effective. Table 3 summarizes their opinions.

TABLE 3
OPINIONS OF KYOTO CITY FIRE DEPARTMENT STAFF

No.	Opinions
1.	Change evacuation route depending on environmental disaster.
2.	Consider evacuation method using emergency transportation route.
3.	Consider both width of road and shortest path.
4.	Change the environmental disaster depending on scale of earthquake.

1. It is rather difficult for administrative staff to be able to completely predict what will happen in earthquakes, and therefore the system needs to take various situations into consideration in verifying various evacuation guidance methods.
2. The administrative staff proposed the use of an emergency transportation route for evacuation, because emergency transportation routes are only for public use and unavailable to general vehicles. This assures the safety of the evacuation to a certain level. This is also related to the next point （3）.
3. The width of roads must be more than 6 meters to avoid congestion. The widest and shortest paths need to be designated. For example, a road may not be useable because of the collapse of buildings or fire. The system needs to take such possible dangers into consideration.

VI. CONCLUSION

This paper shows the importance of disaster countermeasures for tourists, the necessity of a system that considers appropriate evacuation methods in large disaster areas, and presents the structure, and evaluation of such a system. In the future we would like to develop a detailed behavioral model that includes meets, 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. Although the system is applicable not only to Kyoto City but also other tourist destination cities, first of all, we are considering applying the system in Kyoto City. Finally, our heartfelt appreciation goes to Kyoto City Fire Department officials.

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Fig.7: Positions of temporary shelters, staging posts and destinations