ASEAN Journal on Hospitality and Tourism, Vol 13, pp. 137-150
Printed in Indonesia.

A STUDY ON EVACUATION SIMULATION FOR GUIDING TOURISTS IN HIMEJI CASTLE BASED ON A SURVEY OF TOURISTS' INTENTIONS IN EVACUATION AFTER EARTHQUAKE

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Many tourists tend to visit historic areas. Nevertheless, their knowledge about these areas, disaster prevention, and evacuation is not sufficient. Japan has met with several large-scale disasters, namely the Great East Japan Earthquake in 2011, the Great Hanshin-Awaji Earthquake in 1995, and will potentially face the Nankai Trough Quake in the future.

This paper, based on a survey of tourists' intentions in evacuation after an earthquake in Himeji castle, shows an evacuation simulation and the measures for supporting tourists' evacuation. Himeji Castle, the area investigated by this study, is one of the world heritage sites in Japan.

First, this study revealed decision-making rules and used these to categorize tourists. This paper investigated the sources of information that tourists consider before starting evacuation. According to the results of the questionnaire survey, four groups were categorized by analytic hierarchy process and cluster analysis. As a result, many tourists set a high value on information from sign boards and staff of the Himeji castle before starting evacuation. Next, in a similar manner, using analytic hierarchy process, this survey found that many tourists consider information from signboard and staff when choosing evacuation routes, and the respondents were categorized into four groups using cluster analysis.

Second, this study developed an evacuation simulation taking into account the tourists' intentions about evacuation. This study used SOARS, Spot Oriented Agent Role Simulator, as a simulation platform and adopted a Spot-Link type model.

Third, this study simulated six cases that have different evacuee flows near "Bizen-gate" and routes in sightseeing, and evaluated them by transition of the number of evacuees who were able to reach an evacuation area and the number of evacuees who could not move because of bottlenecks. As a result, we found two effective measures for guiding tourists.

tourist, evacuation, multicriteria decision-making, Himeji castle, agent simulation

INTRODUCTION

Background and objective

According to White Paper (2014) on Tourism in Japan, in 2013, there were 421,760,000 tourists who traveled in Japan, including 243,000,000 who travelled for a daytrip. However, Japan has a problem with tourist management during disaster periods. In the

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Great East Japan Earthquake, a travel agency could not contact 900 people who visited damaged areas for traveling and business. However, Japan has a successful case in managing travelers' evacuations in Matsushima city, Miyagi prefecture. The city office in this city guided tourists and gathered them to evacuation areas in the Great East Japan Earthquake, and 1200 tourists could go back home safely within four or five days later (Okubo et al., 2013).

Based on this experience of Japan during earthquakes, it is important to support and guide tourists' evacuation to a place of safety. This study focuses on the measures for guiding tourists to a temporary evacuation area. The objective of this study is to find measures to guide tourists rapidly and safely by agent simulation. Furthermore, there are three processes which include the implication of decision-making based on the questionnaire survey considering multicriteria decision-making, the development of an evacuation simulation model with decision-making, and the evaluation of measures with different evacuee flows and routes in sightseeing.

Himeji castle

This paper used Himeji castle, a world cultural heritage site in Japan, as a case study. Based on the data provided from Himeji castle office, in 2013, there were 880,546 tourists who visited Himeji castle and it is expected that this number of visitors will increase after the completion of renovations.

There are five characteristics of this castle. First, this area is expected to have severe earthquakes, measuring magnitude 8.0 on the scale, by being located North West and South East of the Yamaguchi fault. This fault runs through the north of Himeji city. Second, tourists can enter the castle using only one gateway. Third, there are two routes from the gateway to a tower in the castle. Fourth, before reaching the tower, one has to pass an open space that is called "Bizan-maru". If the tower is crowed with tourists, tourists can wait and make a line there. Furthermore, there are some open spaces, not only Bizen-maru, but also Sanno-maru and so on. Fifth, there are 21 gates and many narrow paths, which can control the number of flows by the width. Himeji castle, which has these characteristics, is a suitable area to study as a historic and tourism area.

DECISION-MAKING OF TOURISTS

Tentative evacuation decision-making

Before starting this study, a tentative decision-making model was developed. This study focuses on evacuation decision-making for developing an evacuation simulation to evaluate guide measures. In Figure 1, evacuees decide whether they should start evacuation or not considering some factors. After starting evacuation, they choose a route which has some factors. They attempt to move to an evacuation area.

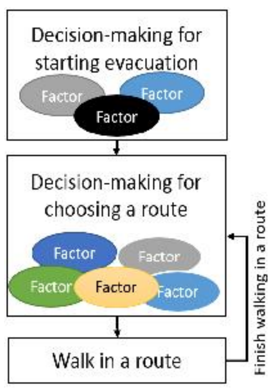


Figure 1. Tentative decision-making model

Decision-making for starting evacuation

In this part, the factors for starting evacuation are described. Kaneda (2010, pp.39-41) told that there are two types of evacuation behaviors, according to Table 1, tourists usually do not have enough mental maps and need guidance through communication and from signboards during disasters. Tourists' evacuation behaviors are the same as

Evacuation Behavior 2. Regarding the work of Tazaki (1988) in a case study of the eruption of Mt. Mihara in 1986, people could not start evacuations by themselves. In his study, about 40 percent of evacuees started evacuation after receiving information from other people: town officers, volunteer fire fighters, family, and neighbors.

Table 1. Types of evacuation behavior (Kaneda, 2010, pp.39-41)

Type	Feature
Evacuation Behavior 1	• Mental map • Evacuee knows a safety place • Rational behavior
Evacuation Behavior 2	• Incomplete Mental map • Evacuee doesn't know a safety place • Irrational behavior • **Guidance by communication and Signboard**

He called this phenomenon the human factor. This is an example which shows that the people around a targeted person are important to affect their decision to start evacuation. From these studies, the factors affecting tourists' initial evacuation are described here. The first factor is an evacuee's own thoughts and intentions, which is called my information. The second factor is other evacuees' information, thoughts, and intentions, which is called others' information. The third factor is the information of staff members and signboards, which is called guide information. This study presumes that these factors have an influence on tourists' decision-making before starting evacuation.

Decision-making for choosing a route

This study applied seven behavioral characteristics of evacuee's when choosing a route in a building from Table 2 (Murosaki, 1993, pp42-44) and found that tourists' decision-making for choosing routes included five characteristics: Homing, Following, Downhill, Guide, and Width. Homing behavior was shown as returning to a route that an evacuee had already walked. Following behavior was shown as the use of a route which more evacuees chose. Then, the nearest choosing behavior was to move to a downhill route. In Japanese castles, a downhill route usually connects to a gateway, but the uphill connects to the castle's tower. Downhill routes were used frequently in this study. Next, 'easiness to see' behavior was shown as moving to a route with signboards and staff guide. Straightness behavior was shown as choosing a wider route. This study applies straight behavior to choosing a wider route because walking wider routes is usually the same as waking along a route. These factors are called Homing, Following, Downhill, Guide, and Width in this paper. However, this study did not consider daily flow behavior and safety equipment behavior because these behaviors are considered for residents and people who know and have the sense of a place.

Table2. Behavioral Characteristics of Evacuee's Route in a building (Murosaki, 1993, pp42-44)

Behavior in Japanese	Behavior in English	Explanation	In this study
Kiso kodo	Homing	Evacuees return to a route that they had already walked.	•A route that an evacuee already had walked. (Homing)
Tuiju kodo	Following	Evacuees follow other evacuees.	•A route that more evacuees had chosen. (Following)
Nichijo cosen heno fukki	Daily flow	Evacuees use a route or stairs that they often used.	
Anzenkiki heno koshitsu	Safety equipment	Evacuees choose a route that is known as a safe route by them.	
Shikinkyori sentakusei	Nearest choosing	Evacuees choose the nearest route, stairs.	•A downhill route (Downhill)
Ekishi keiro sentaku	Easiness to see	Evacuees choose a route and follow signboards that are easy to see.	•A route which Signboard and staff guide (Guide)
Chokushinsei	Straightness	Evacuees go straight on until they reach the end of route	•A wider route (Width)

Decision-making from the literature review

This study developed a tentative decision-making process before conducting a survey in Figure 2. First, evacuees decide whether to start evacuation or not by considering each information source: my information, others' information and guide information. After starting evacuation, they choose a route by considering homing, following, width, downhill, and guide. Second, after walking a particular route to its conclusion, they return to decision making for choosing the next route. Lastly, they repeat this process until they reach an evacuation area. This study considers multi-criteria decision-making during starting evacuation and choosing a route, which was not treated in previous studies (Cui et al., 2013), (Masumoto et al., 2010).

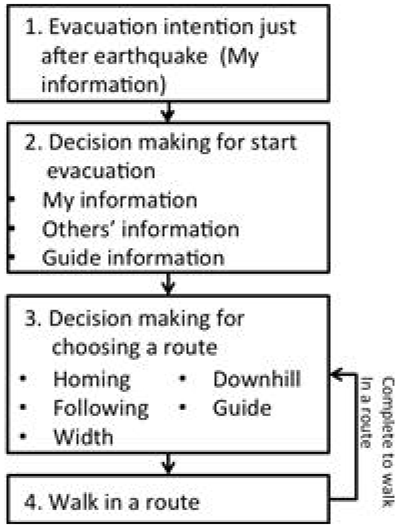


Figure 2. Tentative decision-making

SURVEY ON DECISION-MAKING

Survey outline

A survey based on the mentioned decision-making models was conducted in November 2013 to investigate tourists' intentions after earthquake, tourists' priority of each information, and tourists' priority of each factor about the route. Table 3 shows a composition of the questionnaire. 425 questionnaires were distributed to tourists who visited Himeji castle. We collected 425 questionnaires in Q1, 384 questionnaires in Q2, and 204 questionnaires in Q3.

Table. 3 Questions considering behavioral characteristics.

		Simple number	Question
Q1	Intention	425	What will you do after earthquake? • Stay here • I don't know • Evacuate to somewhere
Q2	Priority about information sources	384	Whose information tourists consider is important after earthquake • Information that I own by myself. • Information that other evacuee own. • Information that staff members and signboards guide.
Q3	Priority about characteristics of route	204	What kind of routes you consider is important to choose after earthquake? • A route that an evacuee already have walked. • A route that more evacuees choose. • A downhill route • A route which staff members and signboards guide • A wider route
Q4	Attribution	425	Gender and age

Result of the survey

In this part, the analysis of evacuees' intentions is presented. Evacuees' intentions after disaster is shown in Figure 3. From this Figure, most respondents (47.29%) answered "Stay there". 83 respondents (19.53%) answered "I don't know". 66.82% of respondents would wait and see around the area after disaster. On the other hand, 141 respondents (33.18%) answered "Evacuate somewhere". 66.82% of tourists intend to stay, but

33.18% of tourists would like to move. Furthermore, this survey asked respondents to describe their expected evacuation areas. Figure 4 presents the answer to this question. Most of them answered Sanno-maru, which is one of the biggest open spaces outside Himeji castle. From this result, Sanno-maru is desirable as a temporary evacuation area.

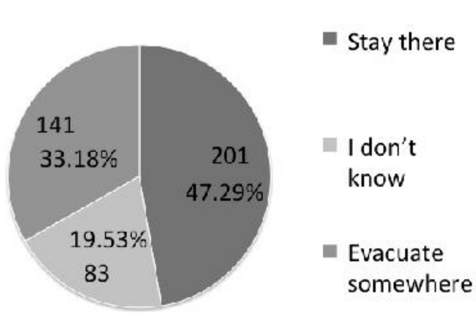


Figure 3. Evacuees' intention

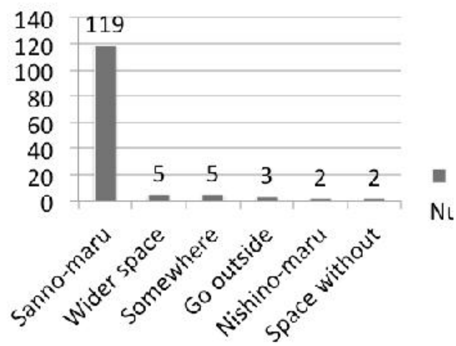


Figure 4. Expected evacuation area for respondent who answered "Evacuate somewhere"

This survey investigated tourists' priority about information sources in decision-making before starting evacuation. First, respondents conducted paired comparison between each information source, which include my information, others' information, and guide information. Second, this paper took a weight for each information source using an analytic hierarchy process. Data that exhibited under 0.15 in C.I. value was removed at that time. Third, these results were classified in four types of tourists by cluster analysis using ward's method.

In Table 4, my information is prior to other information sources for group 1. Then, others' information is more important for group 2 than other information sources. Next, group 3 considers that guide information is the most important. Lastly, Group 4 considers the three type of information fairly.

Table 4 Classification of tourists by Decision-making for starting evacuation

Group	Number	Percent	Explanation	Weight of each information		
				My information	Others' information	Guide information
1	27	7.03%*	Information that I own myself is more important for this group.	0.17*	0.23*	0.60*
2	36	9.38%*	This group considers that other evacuee's information is important.	0.0.65*	0.23*	0.12*
3	250	65.10%*	This group considers that other staff members' and signboard's information is important.	0.17*	0.68*	0.15*
4	71	16.49%*	This group considers three type of information fairly.	0.31*	0.42*	0.28*

* was rounded off to two decimal places

This study investigated tourists' priority about factors of decision-making for choosing a route. In this survey, respondents also conducted a paired comparison between each factor: guide, homing, following, width, and downhill. After that, this paper represented weights for each factor by analytic hierarchy process. Data that exhibited under 0.15 in C.I. value was removed. Next, this study found four tourist groups about which this study can give suitable explanations using ward's method and cluster analysis.

According to table 5, Guide is most important for group A. Then, Group B considers all factors fairly. Following is more important for group C. Next, group D considers that width is important.

From the survey, we developed patterns of tourists' decision-making process. Figure 5 shows the rules of deciding a type of tourists' decision-making considering the results of the survey. First, Agents do not have any effect on intention value, DMS value and DMR value before disaster. After an earthquake occurred, tourists' decision-making can be decided by the following probabilities as presented in Figure 5.

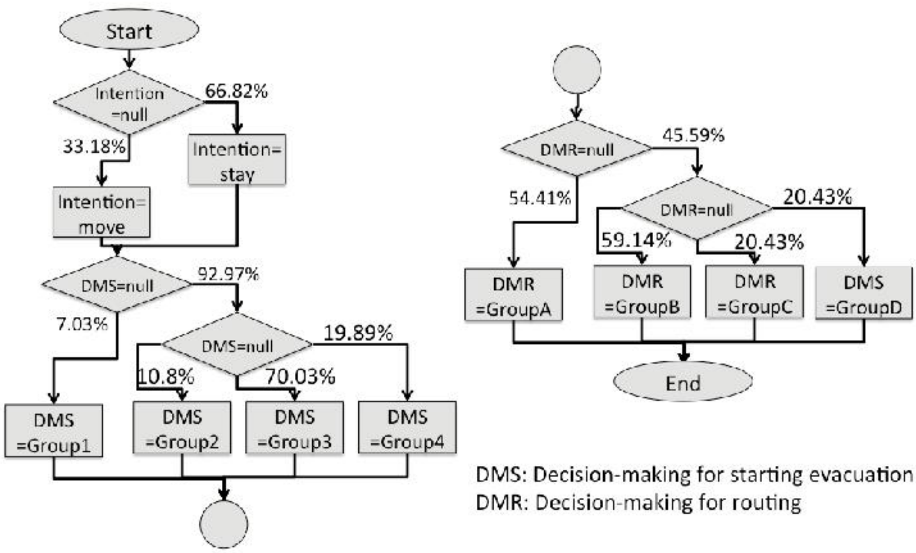


Figure 5. Rules of deciding a type of tourists' decision-making

Table 5 Classification of tourists by Decision-making for choosing a route

Group	Number	%	Explanation	Weight for each factor				
				Guide	Homing	Following	Width	Downhill
A	111	54.41%*	This group considers that a route that staff and signboard guide is important.	0.47*	0.17*	0.13*	0.15*	0.08*
B	55	26.96%*	This group considers five criteria fairly.	0.26*	0.21*	0.19*	0.23*	0.11*
C	19	9.31%*	This group considers that a route that they already have walked is important.	0.25*	0.41*	0.11*	0.15*	0.09*
D	19	9.31%*	This group considers that a wider route is important.	0.20*	0.26*	0.11*	0.43*	0.11*

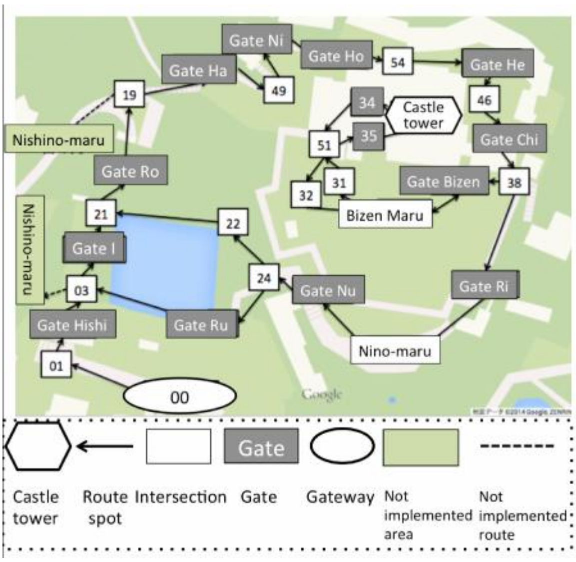
* was rounded off to two decimal places

SIMULATION MODEL

Routes network model in Himeji castle

This study used Spot Oriented Agent Role Simulator, SOARS, as a simulation platform and adopted Spot-link model simulation. This simulation used the concepts of spot and agent.

The routes network is composed of five spots: route spot, intersection spot, gate spot, gateway spot, and stair spot. Route spot means the route where the agents walk. Intersection spot means the junctions between routes where the agents decide which routes to take. Gate spot means gates in the castle, which can limit the number of evacuees entering the gate. Gateway spot means an entrance and exit from which tourists enter Himeji castle. Stair spot means the stairs in a tower of Himeji castle.



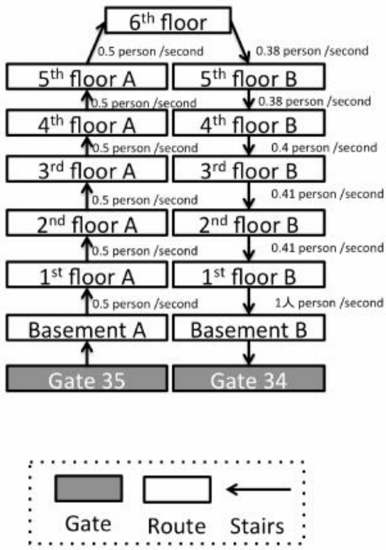


Figure 6. Route network of Himeji castle (Author made from Google Map)

Figure 7. Network of the castle tower (Author made from a hearing survey)

Figure 6 shows a part of the street network in Himeji castle in the simulation. Figure 7 shows a network in Himeji castle's tower. Networks in the castle tower are composed of route spot and stair spot. Table 6 and 7 explain the width and distance of each route spot and the width of each gate spot. Table 8 shows the distance of each route spot of the castle tower. Table 9 shows the number of tourists who can enter Himeji Castle from the gateway spot during opening times.

Table 6. Width and distance of routes

Route Name	Width (Meter)	Distance (Meter)	Route Name	Width (Meter)	Distance (Meter)
R00-01	5	4	R38-Chi	1	14
R01-Hishi	5	7	R38-Bizen	1.9	9.5
R01-03	4.4	7	Bizen maru	10	90
R03-I	4.4	41	R31-37	1.1	34
R03-21	5	8	R34-51	1.5	3
R20-21	4.5	18	R33-51	1.5	3
R19-20	7.6	16	R32-33	1.1	34
R19-Ha	2.7	45	R38-Ri	4.6	52
R49-Ha	2.6	36	Nino maru	6.3	83
R49-Ni	2.7	25	R24-Nu	6	15
RNi-Ha	2.4	23	R22-24	6.6	5
R54-Ho	5	19	R21-22	4.5	80
R54-He	2.5	58	R23-24	2.1	5
R46-He	4	17	R03-Ru	4.2	65
R46-Chi	2.5	15			

Table 7. Width of gates

Gate name	Width (meter)	Gate name	Width (meter)
Gate Hishi	3.8	Gate Chi	1
Gate I	3.1	Gate Bizen	1.9
Gate Ha	2.1	Gate Ri	2.2
Gate Ni	1.5	Gate Nu	2.9
Gate Ho	1.3	Gate Ru	1.6
Gate 34	1.5	Gate 35	1.5

Table 8. Distance of routes in castle tower

Route name	Distance (Meter)	Route name	Distance (Meter)
Basement A	9	Basement B	60
1st floor A	100	1st floor B	6
2nd floor A	200	2nd floor B	0
3rd floor A	0	3rd floor B	25
4th floor A	300	4th floor B	8
5th floor A	4	5th floor B	5
6th floor	100		
Stairs basement to 1st floor	15	Stairs 1st floor to basement	0
Stairs 1st to 2nd floor	15	Stairs 2nd to 1st floor	15
Stairs 2nd to 3rd floor	15	Stairs 3rd to 2nd floor	15
Stairs 3rd to 4th floor	15	Stairs 4th to 3rd floor	15
Stairs 4th to 5th floor	15	Stairs 5th to 4th floor	15
Stairs 5th to 6th floor	15	Stairs 6th to 5th floor	15

Table 9. Number of tourists who enter to Himeji Castle per second

Time zone	Number of tourists who eater to Himeji Castle
9:00-10:00	0.46 tourist per second
10:00-11:00	0.53 tourist per second
11:00-12:00	0.51 tourist per second
12:00-14:00	0.55 tourist per second
14:00-15:00	0.53 tourist per second
15:00-16:00	0.17 tourist per second
16:00-17:00	0.0017 tourist per second

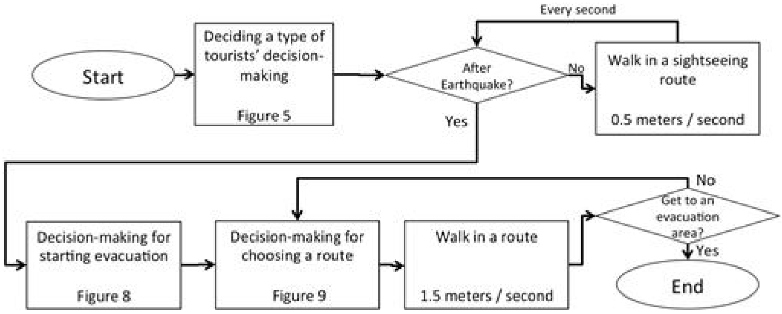


Figure 8. Flow of agents' total processing

Agent model as a tourist

In this part, agents' processes of decision-making were described. Figure 8 is a flow of agents' total processes in this simulation. First, agents were given their types of tourists' decision-making by Figure 6. Second, they followed their decision-making processes before starting evacuation which were explained by Figure 9. Third, they followed their decision-making processes for choosing a route which was explained by Figure 10. Finally, they repeated walking in a route spot and decision-making for choosing a route spot until they reached an evacuation area.

In decision-making processes prior to starting evacuation, agents followed a flowchart of Figure 8, which is based on the survey. Weights of my information, others' information, and guide information are given by table 4.

When agents choose a route, they follow the flowchart shown in Figure 10, which was developed by the survey about tourists' decision-making for choosing a route from a previous chapter. After starting evacuation, they use a part of this flowchart: following, downhill, guide, and homing. The weight of each factor is provided in Figure 5.

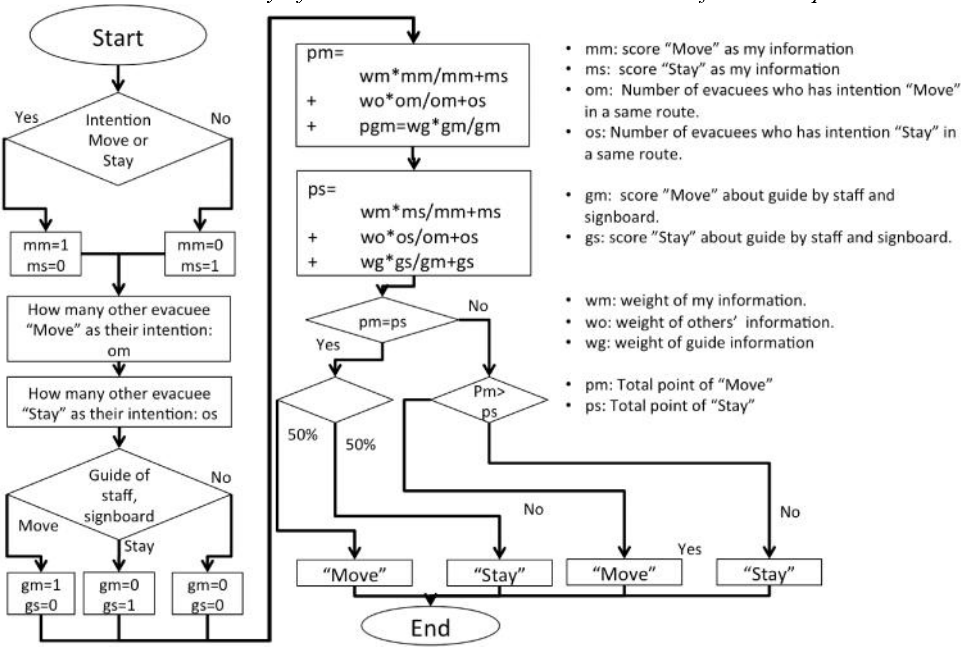


Figure 9. Flowchart of Decision-making for starting evacuation

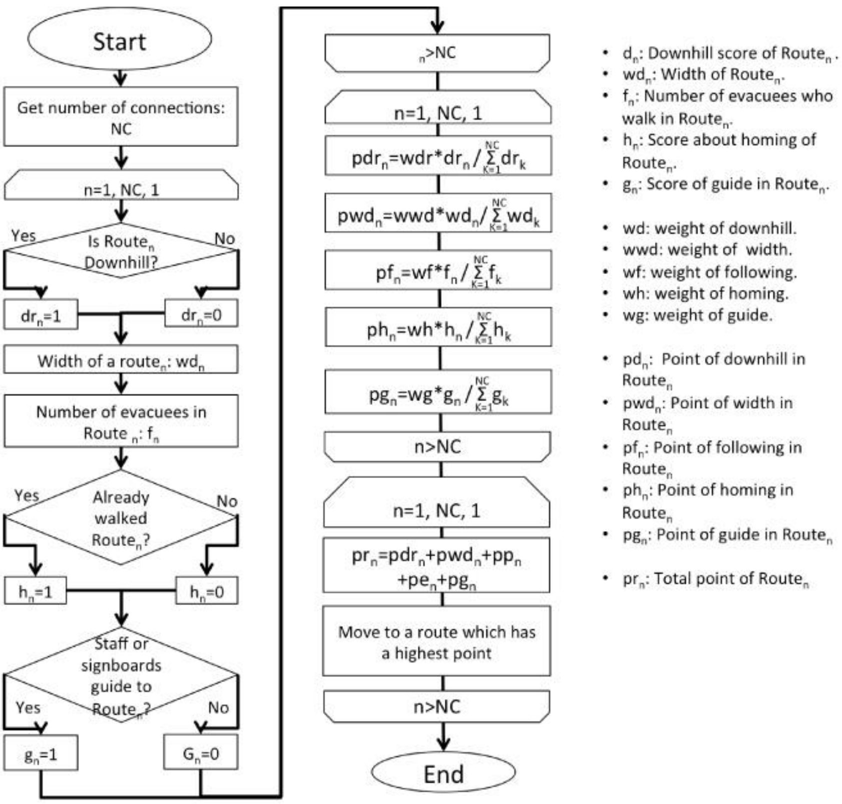


Figure 10. Flowchart of Decision-making for choosing a route

Move inside a route and through a gate

Walking speed is estimated as 0.5 meters per second during sightseeing time and 1.5 meters per second during evacuation. After the agent finishes walking, they move to the process of choosing a route. Furthermore, this simulation considers a limitation of flow from a route spot to a gate spot. The limitation is shown by (1).

Q=k×wdn×T ・・・（1）

Q: Limitation of flow

T: Second

k: Coefficient (Sightseeing time: 0.5persond /meter•second, Evacuation time：1.5 person /meter•second)

wdn: Width of Routen

If the flow exceeds the limitations of the gate, agents must move back to a spot where they were just before and they try to move to the gate again in the next step.

SIMULATION EXPERIMENT AND RESULTS

Cases for the simulation

This study simulated six cases (Table 10) that have different evacuee flows at 38 spots and different routes in sightseeing, and evaluated them by transition of the number of evacuees who reach the evacuation area and the cumulative number of evacuees who cannot move because of bottlenecks at gates. In clockwise sightseeing routes, agents move from 00 spot to castle tower via 21, 19, 49, 54, 46, 38, 51, and 35 spot during sightseeing. From the caste tower to 00 spot, they move via 34, 51, 32, 38, 24, 22, 21 and 03 spot. On the other hand, anticlockwise sightseeing routes mean that agents move to the castle tower from 00 spot via 21, 22, 24, 38, 32, 51, 34 and to 00 spot from the castle tower via 35, 51, 31, 38, 46, 54, 49, 19, 21 and 03.

Table 10. Cases

	Sightseeing route	Evacuee flow by guide at 38 spot
1	Clockwise	Gate Ri
2	Clockwise	Gate Chi
3	Anticlockwise	Gate Chi
4	Anticlockwise	Gate Ri
5	Anticlockwise	Gate Ri and Gate Chi
6	Clockwise	Gate Ri and Gate Chi

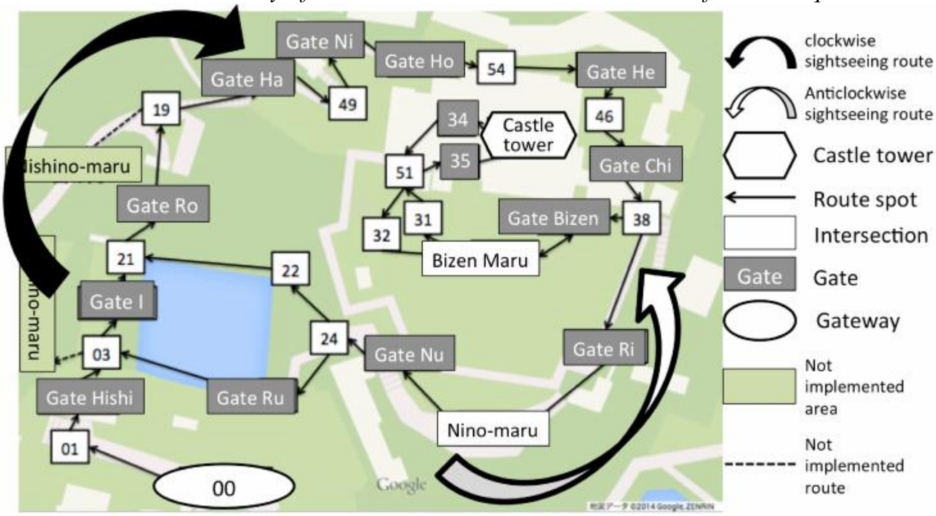


Figure 11. Clockwise and anticlockwise sightseeing route

Settings and limitations of this simulation

This study regarded agent's getting to 00 spot as their completion of evacuation, although Sanno-maru is also considered as an evacuation area. Himeji castle opens at 9:00 am and tourists enter for sightseeing. The earthquake occurs at 12:00 in the simulation. 4,000 agents are in the castle at that time.

First, this simulation does not implement Nishino-maru because most tourists do not go there. Second, all evacuees move outside from the castle tower during evacuation time. They do not follow the evacuation decision rules in the castle tower. Third, this simulation does not consider the damage to buildings and the obstacles blocking routes. Fourth, this simulation does not consider the effect of downhill routes and uphill routes on walking speed.

Results and Discussion

Figure 12 and Table 11 show the result of each case from a viewpoint of the number of evacuees who reach the evacuation area. From this result, Case 2, 4, and 5 are better measures than the remaining cases because more agents could complete their evacuation.

Table 12 shows the result of each case from the viewpoint of a cumulative number of evacuees who cannot move because of bottlenecks. Regarding the smallest of the cumulative numbers, case 5, case 4, and case 2 are ranked, respectively.

From these results, this study reveals two interesting measures, case 4 and 5 which both had an anticlockwise sightseeing route and guided tourists to a route where they had already walked.

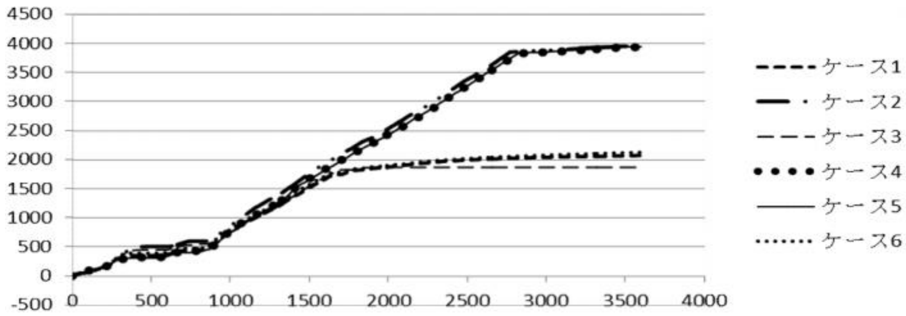


Figure 12. Number of evacuees who complete to evacuate by cases

Table 11. Number of evacuees who complete to evacuate by cases every 600 seconds

	0 seconds	600 seconds	1200 seconds	1800 seconds	2400 seconds	3000 seconds	3600 second
Case 1	0	371	1060	1819	1980	2040	2073
Case 2	**0**	**507**	**1237**	**2249**	**3202**	**3883**	**3950**
Case 3	0	451	1086	1853	1871	1871	1871
Case 4	**0**	**350**	**1104**	**2136**	**3100**	**3848**	**3934**
Case 5	**0**	**339**	**1094**	**2145**	**3102**	**3854**	**3942**
Case 6	2	412	1116	1844	2001	2079	2127

Table 12. Cumulative number of evacuees who cannot move every 600 seconds

	0 seconds	600 seconds	1200 seconds	1800 seconds	2400 seconds	3000 seconds
Case 1	0	71	13350	129216	667004	1632932
Case 2	**0**	**2638**	**10232**	**11589**	**12641**	**13041**
Case 3	0	609	28996	189784	861210	1931178
Case 4	**0**	**17**	**473**	**474**	**485**	**491**
Case 5	**0**	**38**	**376**	**377**	**392**	**398**
Case 6	0	89	10881	136148	698167	1649424

It is conceivable that two reasons led to these results. The first reason is related to homing behavior. Before the stream of crowd is taken into account, homing behavior was assumed to have an effect on agents' decision-making. The second reason is related to gates. Gates in a route where agents were guided after the earthquake and had walked during sightseeing are wider than gates in another route.

CONCLUSION

Today, guiding tourist under disasters is one of the urgent issues. In this paper, evacuation simulation models were developed for a historic area of tourism, Himeji castle, considering multi-criteria decision-making. This paper also gives two better measures for guiding tourists during earthquakes using six cases that have different evacuee flows at 38 spot and different routes in sightseeing. The results of this study are as follows:

(1) The sightseeing route is one of the important factors that affect the smoothness of tourists' evacuation guidance. Two cases of anticlockwise sightseeing routes have the higher number of evacuees who reach the evacuation area than cases of clockwise sightseeing routes.

(2) Evacuees' flow is also another important factor which affects the smoothness of tourists' evacuation guidance. In cases where tourists have been guided to a route where they have already walked, the number of evacuees who reach the evacuation area became higher and the number of evacuees who cannot move became lower.

This simulation model can be used only for Himeji castle today. However further studies needed to generalize further studies to use other tourism areas.

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