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Consciousness Analysis of Evacuation from Complex Disaster

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Abstract

Approximately In this study, Adachi-ku Senju district in Tokyo was selected as an investigated district because this district has been designated by the Tokyo Metropolitan Government as an area having high fire and flood risks. Questionnaire survey was conducted for the residents in this district to collect data on level of recognitions about disaster damage estimates and recommended evacuation method. Moreover, stated-preference for disaster evacuation was also investigated. The obtained stated-preference data was utilized to estimate model describing citizen's disaster evacuation behavior that was formulated by nested-logit mode with three hierarchies. First hierarchy is evacuation/no evacuation choice behavior, second hierarchy is vertical/horizontal evacuation choice behavior and third hierarchy is evacuation place choice behavior. The evacuation behavior model was estimated by maximum likelihood estimation method and it was utilized to forecast the number of evacuee under certain disaster situation such as outbreak of the earthquake disaster and imminence of flood. Level of safety of evacuation method was evaluated using the pedestrian crowd evacuation simulation built in this study. The safety of each evacuation method was verified in terms of evacuation completion time, the risk of encountering danger during evacuation such as approaching to fire spot, walking in excessively crowded space, collision of falling object caused by aftershock, walking in inundated area, and etc.. It is expected that the results of this study is utilized as basic information to examine the safer evacuation method of the investigated district.

Keywords: evacuation behavior model, stated preference, nested-logit model, pedestrian crowd simulation

1. INTRODUCTION

Four years have passed since the Great East Japan Earthquake of March 11, 2011 which brought serious damage in the Tohoku district. Previous disaster prevention measures were reviewed and the actions to reduce disaster damage is progressed. In addition, the correspondence to the complex disaster also is to be considered. Senju district in Adachi-ku is focused on in this study since this district is evaluated by the national and local organizations to be high-risk of the different disaster such as earthquake and flood.

According to the Seventh Community Earthquake Risk Assessment Study by the Tokyo Metropolitan Government, this districts is appointed to the area with high combined risk of building-collapse and fire due to earthquakes. In addition, the Ministry of Land, Infrastructure and Transport shows that there is an area flooded more than 5m in this district when Arakawa overflowed.

As described above, there are many problems for disaster reduction in this district. Therefore, this study research on the disaster evacuation of the residents in this district. Evacuation behavior model was built and the number of evacuee was estimated under the different disaster situations. Moreover, the evacuation safety is evaluated by using a pedestrian crowd simulator.

2. STATED PREFERENCE SURVEY

Questionnaire survey was conducted to investigate evacuation behavior of the residents. Stated preference experiment was adopted for the survey since there was no data about revealed preference for evacuation.

Figure 1 shows an example of the stated preference experiment. Each respondent is required to answer the evacuation behavior under the presented disaster situation.

The disaster situation is different by setting status of disasters. Possibility of fire spread to the residence, possibility of flood, status of road congestion, suffered state of urban lifeline were considered as the variables of the disaster situation. Respondents answered their expected evacuation behavior under five different situations.

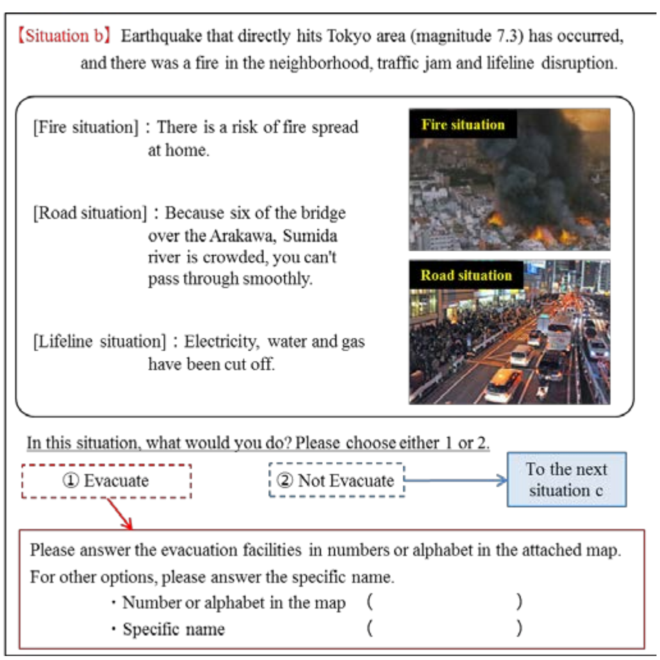

Figure 1: Example of the question about stated preference

3. ESTIMATION OF EVACUATION BEHAVIOR MODEL

3.1 Hierarchy of evacuation behavior

Evacuation is conducted by corresponding to the status of disaster. Figure 2 shows hierarchical structure of disaster evacuation. Decision making for evacuation is conducted from the top to the bottom.

At first an evacuee decides whether to go out from the residence or not. Secondly, the evacuee decides whether to conduct horizontal evacuation or to conduct vertical evacuation. Finally, the evacuee decides the evacuation facility to go. However, in the case of an earthquake disaster, the second stage regarding the decision regarding horizontal/vertical evacuation is not considered.

For estimating mathematical models of evacuation behavior, the discrete choice model was utilized in this study. To consider the hierarchical structure of the behavior, nested logit model was applied. Parameter estimation was executed from the bottom to the top according to the estimation method of nested logit model.

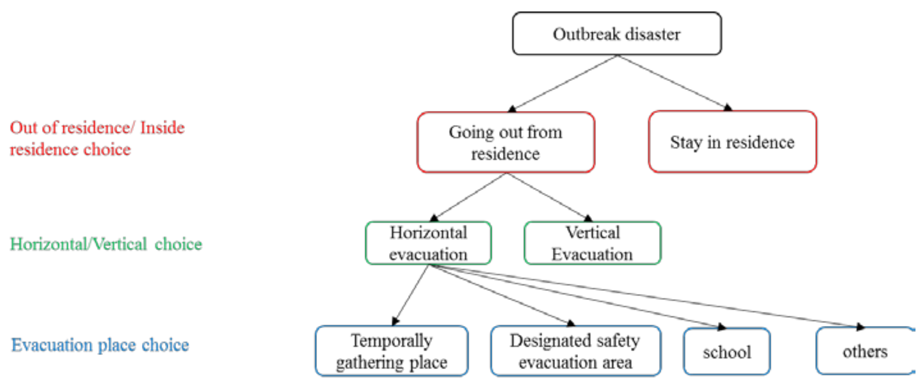

Figure 2: Hierarchical structure of disaster evacuation

3.2 Evacuation place choice model

3.2.1 Choice set and explanatory variables

Alternatives of evacuation place choice were set as temporally gathering place, designated safety evacuation area, school not designated for temporally gathering place and others.

Choice possibility of these four facilities was set by the following methods. After measuring the distance from the residence (center of gravity of the residential zone) to the facilities to be chosen, more than 80 % of the facilities were in less than 500m. Therefore, the evacuation facilities located within less than 500m were from the center of the zone were considered as alternatives.

The explanatory variables of this model are described in the Table 1. Moreover, the dummy variables of each facilities are considered. If there are plural temporally gathering places in the residential zone, the means of distance and the number of floors are used for the variables.

Table 1: Explanatory variables of evacuation place choice model

Explanatory variables	Measurement
Distance to evacuation place	Minimum distance from the zone to the place(m)
Number of floors of evacuation place (floors)	Number of floors of the facilities (floors)
Decrease of building collapse risk	Difference between the building collapse risk at the residence and that of the evacuation place (building/ha)
Decrease of fire risk	Difference between the fire risk at the residence and that of the evacuation place (building / ha)
Decrease in the inundation depth	Difference between inundation depth at residence and that of the evacuation place (m)

3.2.2 Estimation result

On the occasion of parameter estimation, the respondent whose individual attributes such as place of residence, age and gender were unknown were removed from the dataset for the estimation.

Table 2 shows the estimation result of the evacuation place choice model. There are three models presenting evacuation behavior under different situation such as possibility of fire spread, possibility of flood and possibility of complex disaster. These model can explain the reason why certain place was chosen for the evacuation place. T-statistics indicates statistical significance of each coefficient.

Table 2: Estimation result of Evacuation place choice model

Disaster situation	Fire spread		Flood		Complex disaster	
Explanatory variables	coefficient	t-statistics	coefficient	t-statistics	coefficient	t-statistics
Distance to evacuation place(m)	-0.0022	-5.17	-0.0030	-3.35	-0.0020	-4.19
Number of stories of evacuation place			0.0053	0.023	0.013	0.079
Decrease of building collapse risk (building / ha)	0.23	6.28			0.14	2.39
Decrease of fire risk (building / ha)	-0.01	-0.31			0.024	0.95
Decrease of inundation depth (m)			4.41	0.097	0.79	3.13
Constant term for designated safety evacuation area	0.45	0.77	-3.04	-0.44	-0.61	-0.70
Constant term for school	1.58	3.68	1.90	1.32	0.94	0.93
Constant term for others	2.48	3.85	1.22	1.25	0.44	0.69
Initial likelihood	-195.01		-95.15		-111.49	
Last likelihood	-97.98		-28.79		-59.94	
Likelihood ratio	0.50		0.70		0.46	
Adjusted likelihood ratio	0.47		0.63		0.39	
Hitting ratio (%)	75.8		72.9		83.9	
Number of samples	179		96		112	

3.3 Evacuation direction choice model

3.3.1 Definition of direction

In the questionnaire survey, respondents were required to answer the floor level for the evacuation. If this answer is same level of respondent's residence, this respondent evacuates to the higher floor of the residence. In this study, such a vertical evacuation in the residence is not include vertical evacuation. In other words, evacuation by moving out from residence and going to upper floor of neighboring building is defined as vertical evacuation in this study.

3.3.2 Explanatory variables and estimation result

The explanatory variables of this model are described in the Table 3. Beside these variables, constant term for vertical evacuation is considered.

Binary logit model is applied to estimate evacuation direction model which can explain the reason why evacuee choose vertical evacuation and horizontal evacuation.

The estimation result shown in Table 4. There are two models presenting evacuation behavior under different situation such as possibility of flood and possibility of complex disaster.

Table 3: Explanatory variables

Explanatory variables	**Measurement**
Logsum utility	Expected value of the maximum utility for evacuation place choice.
Dummy variable of multistory building	If the building is with more than four floor, set to 1 Otherwise, set to 0

Table 4: Estimation result of vertical/horizontal choice model

Disaster situation	**Flood**		**Complex disaster**	
Explanatory variables	**coefficient**	**t-statistics**	**coefficients**	**t-statistics**
Logsum utility	0.05	0.47	0.15	0.75
Dummy variables of multistory building	3.00	6.58	0.18	4.42
Constant term (vertical evacuation)	-1.94	-6.26	-2.89	-7.21
Initial likelihood	-90.15		-68.65	
Last likelihood	-62.63		-55.95	
Likelihood Ratio	0.31		0.19	
Adjusted likelihood ratio	0.27		0.14	
Hitting ratio (%)	83.1		84.0	
Number of samples	142		156	

3.4 Move/Stay choice model

At first, evacuee must decide whether to going out from the residence or to stay in the residence. In this study, the binary logit model was utilized to estimate this move/stay choice model. The explanatory variables of this model are described in the Table 5. Beside these ten variables, constant term for evacuation by going out from the residence is considered. The reason why two kind of logsum variables are considered is the difference of evacuation behavior under the disaster with and without the possibility of flood. The result of parameter estimation is shown in Table 6.

Table 5: Explanatory variables

Explanatory variables	Measurement
Dummy variables of elder person	Dummy variables (64 years old or older)
Number of stories in the residence	Number of floors of the residence
Cognition situation of earthquake damage	When earthquakes directly under North Tokyo Bay has occurred, whether you are aware of the expected seismic intensity of the district (If you are aware, set to 1)
Cognition situation of flood damage	In the case of dike break of Arakawa river, whether you are aware of the expected inundation height of the residence (If you are aware, set to 1)
Logsum utility of evacuation place choice	Expected value of the maximum utility of evacuation place choice
Logsum utility of evacuation direction choice under flood risk	Expected value of the maximum utility of evacuation direction choice
Dummy variables (Fire spread)	Setting condition of SP survey
Dummy variables (Flood)	Setting condition of SP survey
Dummy variables (Traffic jam)	Setting condition of SP survey
Dummy variables (Lifeline disruption)	Setting condition of SP survey

Table 6: Explanatory variables

Explanatory variables	coefficients	t-statistics
Dummy variables of elder person	-0.53	-3.42
Number of stories in the residence	-0.16	-5.77
Cognition situation of earthquake damage	0.32	2.11
Cognition situation of flood damage	-0.46	-2.24
Logsum utility of evacuation place choice	0.91	7.26
Logsum utility of evacuation direction choice under flood risk	0.79	5.60
Dummy variables of disaster situation (Fire spread)	4.03	5.91
Dummy variables of disaster situation (Flood)	-0.52	-1.44
Dummy variables of disaster situation (Traffic jam)	-2.14	-5.42
Dummy variables of disaster situation (Lifeline disruption)	-1.93	-4.87
Constant term (Evacuation by going out the residence)	0.10	0.72
Initial likelihood	-879.48	
Last likelihood	-780.15	
Ratio of likelihood	0.113	
Corrected ratio of likelihood	0.100	
Hit ratio (%)	65.5	
Number of samples	1305	

4. ESTIMATION OF THE NUMBER OF EVACUEE

Three kinds of model estimated previous chapter were utilized to estimate the number of evacuees under assumed disaster situation.
Estimation was executed by zone and age group (less than 70/ more than 70).
The population in residential zone is based on the national census in 2010 and the mean of the number of floors of residence in a zone is used. Cognition situations of the earthquake and flood damage are both set 0.5.
Table 7 shows the number of evacuees under different disaster situation.
Moreover it shows the number of evacuees by evacuation place and evacuation. These estimates are to be input data of pedestrian crowd evacuation simulation.

Table 7: Estimation of the number of evacuees

		Case1	**Case2**	**Case3**	**Case4**	**Case5**	**Case6**
Disaster situation (○:Considered)	**Fire spread**	○	○			○	○
	Flood risk			○	○	○	○
	Traffic jam		○		○		○
Horizontal evacuation	Temporary gathering place	21,876	21,139	30,349	25,570	11,770	10,283
	Designated safety evacuation area	1,222	1,186	12,066	10,550	33,444	28,191
	School	45,007	43,674	242	194	15,212	13,466
	Others	4,819	4,706	5	4	6,474	5,466
Evacuees (horizontal evacuation)		72,923	70,704	42,662	36,318	66,900	57,406
Evacuees(vertical evacuation)		0	0	28,425	23,333	4,308	3,687
Staying at home		320	2,539	2,156	13,592	2,035	12,150
Total number of people in Senju district		73,243	73,243	73,243	73,243	73,243	73,243

5. EVALUATION OF THE EVACUATION METHOD

In this chapter, evacuation method is evaluated by using CrowdWalk that is a multi-agent simulator developed by the National Institute of Advanced Industrial Science and Technology (AIST) of Japan.
In this study, effectiveness of the temporary gathering place for safer evacuation was examined. The evaluation indices are mean of travel time to the designated evacuation area and mean time when evacuee cannot move by pedestrian congestion.
Three scenarios were prepared for the examination as follows.
First scenario is the situation that all the residents evacuate directly to the designated safety evacuation area at once. Second scenario is the situation that all the residents evacuate to the temporary gathering place for the first stage and move to the designated safety evacuation area after certain time has passed.

The third scenario is the situation that scenario 1 and scenario 2 is mixed in half-and-half. Figure 3 shows the screen shot of the pedestrian simulation.

Meanwhile, Figure 4 shows the evaluation results of evacuation safety. As seen in the figure, the scenario 2 has better performance compared to the scenario 1. It demonstrates that the evacuation to temporary gathering place might be a good evacuation method.

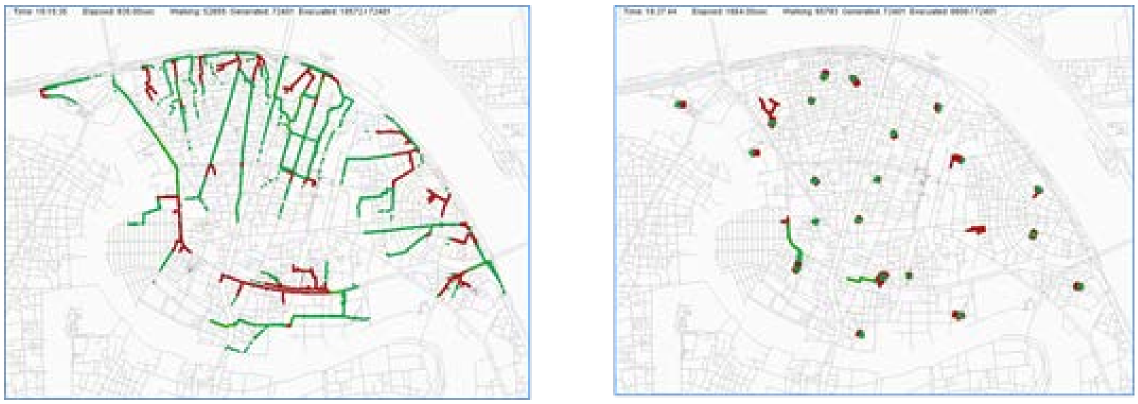

Figure 3: Screen shot of the CrowdWalk (left: Scenario 1, right: scenario 2)

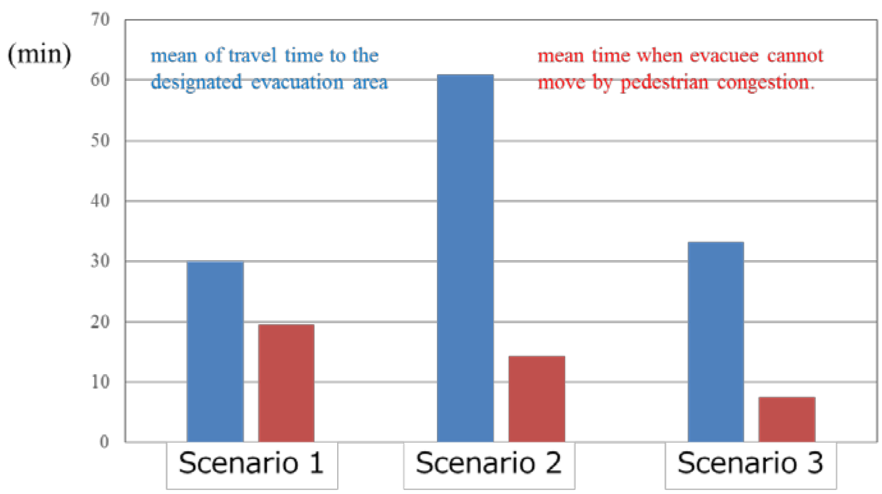

Figure 4: Evaluation of the safety of evacuation method

6. CONCLUSION

In this study, Adachi-ku Senju district in Tokyo was selected as investigated district. Questionnaire survey was conducted for the residents in this district. The stated-preference data for disaster evacuation was utilized to estimate models describing citizen's disaster evacuation behavior. The evacuation behavior models were estimated and it was utilized to estimate the number of evacuee under certain disaster situation. Level of safety of evacuation method was evaluated using the pedestrian evacuation simulation. The safety of each evacuation method was verified in terms of evacuation completion time and time length in pedestrian congestion. It is expected that the results of this study is utilized as basic information to examine the safer evacuation method of the investigated district.