Modeling of Recognition Degree of Refuge Areas by Kyoto City Residents in Post-Earthquake Fire Event

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ABSTRACT

In this study, a model for recognition degree of refuge areas by Kyoto City residents in post-earthquake fire event was developed based on the data obtained by an interview survey. When a large earthquake hits a city in Japan, a tremendous number of evacuees may wander around in urban area escaping from hazards due to conflagrations following the earthquake. We have been developing a simulation model for city evacuation of residents in post-earthquake fire as a tool to evaluate effectiveness of evacuation safety measures. For the further refinement, it is important to accurately estimate evacuation destination of residents considering bias of recognition degree of refuge areas. The interview survey was carried out at 104 spots on busy streets in Kyoto City and replies from 2,267 residents were collected from 1 September 2009 to 30 November 2009. In the interview, the names of open-spaces recognized as evacuation destination were asked having the subjects imagine that conflagrations had taken place in urban area. The governing factors of recognition degree of refuge areas were identified and evacuation destination of residents was formulated by adopting a probabilistic model.

KEYWORDS: evacuation, interview survey, refuge area, post-earthquake fire, Kyoto City.

NOMENCLATURE LISTING

d	dummy variable	s	distance (m)
F	cumulative distribution function	t	duration of residence (year)
L	likelihood function	X	random variable
M	number of interviewed residents	**Greek**	
N	number of refuge areas	α	constant
P	probability	β	constant
R	correlation coefficient	Φ	potential
S	area (ha)	Θ	threshold

INTRODUCTION

When a large earthquake hits a city in Japan, a tremendous number of evacuees may wander around in urban area escaping from spread of fire following the earthquake, which often involves thousands of buildings. For ensuring residents' safety from the fires, it is essential to implement effective evacuation safety measures in advance. As one of the measures, existing open-spaces in urban area have been designated by local government of Japan as the refuge areas against conflagrations following a major earthquake. For validating the effectiveness of such measure, i.e., whether the refuge areas are able to accommodate all of the potential evacuees, it is important to predict a big picture of city evacuation in expected post-earthquake fire scenarios.

We have been developing an agent-based model for city evacuation of residents in post-earthquake fire. The model has been validated by reconstructing the evacuation in the Kanto Earthquake Fire in 1923, where the spatial distribution of fatalities calculated by the model was similar to the survey report [1–2]. It is reported that evacuees selected well-known spacious parks as their destination among several options at that time; for example as many as 400,000 evacuees gathered at Imperial Palace Park in Tokyo City. However in the simulation, such difference in the recognition level among the refuge areas was not considered, i.e., residents recognized all of the refuge areas as the potential destination. In order to predict the evacuation behavior more reasonably, it is essential to incorporate effect by bias of recognition degree of refuge areas.

Several researches regarding evacuation destination of residents in post-earthquake fire have been carried out. They are classified into two groups in terms of research methodology: (1) analysis of the existing data regarding the past evacuation case [3]; and (2) questionnaire survey on residents' attitude [4]. The advantage of these researches is to provide the basic data regarding the evacuation destination of residents in the target area. However, there is a difficulty that decision structure of evacuation destination due to recognition degree of refuge areas is not discussed and the data is not available for the simulation by the present model. Thus, it is essential to develop a method which can predict evacuation destination of a resident considering recognition degree of refuge areas.

In this study, a model for recognition degree of refuge areas by Kyoto City residents in post-earthquake fire event was developed based on the data obtained by an interview survey. In this paper, the survey data was analyzed to identify the governing factors of recognition degree of refuge areas. Then the recognition degree was formulated considering the factors and validated by using the survey data.

INTERVIEW SURVEY TO KYOTO CITY RESIDENTS

The refuge areas against conflagrations designated by local government of Kyoto are listed in Table 1, whose locations are indicated by box symbols in Fig. 1 [5]. Note that the capacity of the refuge area is calculated by dividing available area for evacuation by the area required by one evacuee which is assumed to be $2.0m^2$. The number of the refuge areas in Kyoto City is 67 and all of them ensure more than 1ha area available for safe evacuation from radiant heat from fires. Several historical open-spaces, such as Imperial Palace Park of Kyoto, Nijo Castle, Kinkakuji Temple and Ninnaji Temple, are also included among the designated refuge areas. One of the features of their locations is that many of them are located along the rivers and skirts of mountain and few of them are inside densely-built area.

Outline of Survey

The outline of the interview survey is shown in Table 2. The survey was carried out on the streets of Kyoto City in the daytime from 1 September 2009 to 30 November 2009. The number of the spots where the interview was conducted was 104, whose locations are indicated by circle symbols in Fig. 1. The interview spots were allocated on busy intersections at roughly 500m intervals in the area bounded by Higasiyama
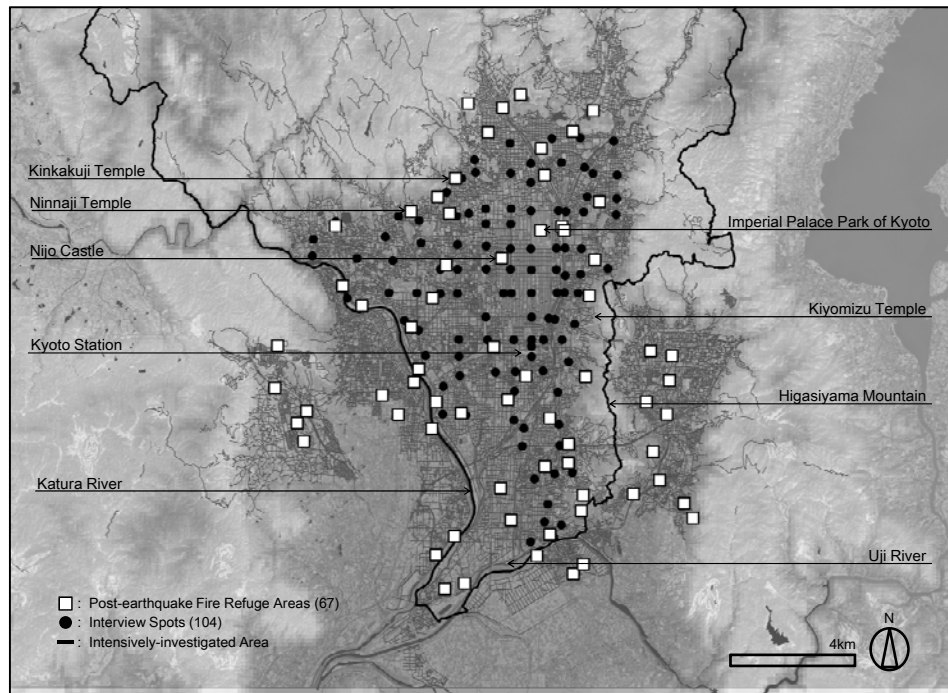

Fig. 1. Locations of refuge areas designated by local government of Kyoto.

Table 1. List of refuge areas designated by local government of Kyoto.

ID	Region	Name of post-earthquake fire refuge area	Class	Site (ha)	Available (ha)
1	Kita	Golf course of Kyoto-Nisikamo	other	40.0	39.0
2		Omiya traffic park	park	2.0	1.2
3		Kinkakuji temple	historical	17.5	1.0
4		Ritumeikan university ground	school	10.0	1.8
5		Rakusei high school ground	school	1.5	1.5
6		Golf cource of Kyoto-Kamigamo	other	55.6	39.0
7	Kamigyo	Imperial palace park of Kyoto	historical	87.0	34.7
8	Sakyo	Kyoto botanical garden	other	31.2	28.0
9		Takaragaike park	park	30.0	14.0
10		Kyoto university ground	school	11.8	4.3
11		Okazaki park	park	4.5	4.5
12		Takaragaike sports space	park	7.0	5.6
13	Nakagyo	Nijo castle	historical	21.8	7.0
14		Shimadzu corporation ground	other	20.5	2.8
15	Higasiyama	Hiyosigaoka high school ground	school	12.5	4.7
16	Simogyo	Umekoji park	park	22.7	10.0
17	Minami	Tonoda park	park	3.5	1.7
18		Kamitoba park	park	1.7	1.7
19		Kisyoin park	park	9.9	7.8
20		Tonan high school ground	school	1.4	1.0
21		Katura garrison	other	37.4	1.0
22		Kuzebasi western park	park	3.1	3.1
23	Ukyo	Ninnaji temple	historical	14.0	1.3
24		Nisikyogoku athletic park	park	15.0	7.2
25		Saiin park	park	2.6	2.3
26		Bukkyo university ground	school	18.0	18.0
27	Husimi	Kyoto police school ground	school	12.4	3.0
28		Fire academy ground	school	11.3	5.4
29		Kyoto university of education	school	11.0	5.3
30		Momoyama imperial mausoleum	other	76.0	21.7
31		Husimi park	park	2.0	1.9
32		Simotoba park	park	2.0	1.9
33		Misu park	park	2.2	2.2
34		Ogurisu junior high school ground	school	3.5	1.3
35		Rituryo junior high school ground	school	3.2	1.1
36		Kasugaoka junior high school ground	school	3.2	1.3
37		Hino outdoor center	other	1.6	1.6
38		Mukaijima-south elementary school ground	school	8.7	5.6
39		Mukaijima junior high school ground	school	7.0	2.1
40		Mukaijima-Hujinoki elementary school ground	school	5.0	4.9
41		Husimi-Kitahori park	park	5.4	3.7
42		Hadukasi athletic park	park	10.4	2.8
43		Kyoto driving license examination ground	other	8.9	5.5
44		Yokooji athletic park	park	13.0	12.8
45		Kyoto racetrack	other	18.0	12.1
46		Hukakusa junior high school ground	school	9.9	1.5
47	Yamasina	Yamasina central park	park	4.0	2.0
48		Higasiyama high school ground	school	3.0	1.3
49		Higasino park	park	6.3	3.9
50		Rakuto driving school	other	1.7	1.6

Table 1 (continued). List of refuge areas designated by local government of Kyoto.

ID	Region	Name of post-earthquake fire refuge area	Class	Site (ha)	Available (ha)
51	Yamasina	Ryukoku university ground	school	6.0	5.4
52		Kansyuji park	park	4.4	3.8
53		Katura high school ground	school	5.4	1.8
54		Katuragawa junior high school ground	school	4.8	2.4
55		Obatagawa central park	park	9.0	9.0
56	Nisikyo	Rakusei junior high school ground	school	6.0	2.6
57		Takenosato elementary school ground	school	7.3	2.2
58		Katurasaka elementary school ground	school	5.9	5.8
59		Kyoto city university of arts	school	7.2	3.4
60	—	Right-bank of Kamo river (upper part)	river	2.3	2.3
61	—	Right-bank of Kamo river (middle part)	river	5.6	4.0
62	—	Right-bank of Kamo river (lower part)	river	3.1	3.1
63	—	Left-bank of Kamo river (lower part)	river	3.2	2.7
64	—	Maruyama park	park	13.0	7.9
65	—	Left-bank of Katura river (lower part)	river	8.0	8.0
66	—	Left-bank of Katura river (middle part)	river	7.0	6.3
67	—	Right-bank of Katura river (upper part)	river	15.5	13.7

Table 2. Outline of interview survey.

Investigation style	Interview			
Investigation period	Sep. 1st, 2009 – Nov. 30th, 2009 (daytime)			
Number of interview spot	104 (on the streets)			
Number of subjects	2,939 (residents : 2,267 tourists : 271 other : 401)			
	Age	Male	Female	Total
	18 – 25	198	201	399
Breakdown of residents (age and sex)	26 – 35	159	172	331
	36 – 45	133	164	297
	46 – 55	110	141	251
	56 – 65	186	185	371
	66 –	302	316	618
Number of subjects at each spot	10 – 33 : [male, female] and [young, middle, old]			

Mountain, Uji River and Katura River. At each interview spot, pedestrians were classified into 6 categories except foreigners and people under 18: [male, female] and [young-age, middle-age, old-age], and 5 subjects at each category were selected for avoiding the bias of sex and age. As a result, the number of the interviewed residents was 2,276. The breakdown of the interviewed residents is shown in Table 2, where proportion of old residents over 65 was relatively large. The number of the interviewed residents at each interview spot was in the range from 10 to 33, and the mean value was 21.8. Especially near the tourist site and business district, majority of the subjects were visitors for sightseeing and business, so that the interviewed residents were few.

Details of Interview

The flow of the interview is shown in Fig. 2 with the orally-asked questions. The questions to the subjects consist of two parts: (a) question on evacuation destination; and (b) question on attributes of the subject. The procedure of the interview is described as follows:

1. Two pictures of the conflagration scenes in Kobe Earthquake in 1995 were shown to the subject in order to make all the subjects share common image for the fire. Then we requested the subject to

imagine the situation that conflagrations had taken place in urban area and buildings around the interview spot were burning.

2. Assuming that the subject had to evacuate from the interview spot to a refuge area in urban area, the name or location of the destination was asked to the subject without showing any information about the refuge areas. In addition, the following questions were asked: (a) the time required to reach the destination on foot from the spot; (b) the direction of the destination from the spot; and (c) the reason of the choice.

3. The above question was repeated until the subject answered 5 destinations at a maximum. Then, the attributes of the subject such as the sex, age and duration of residence in Kyoto City were asked to complete the interview.
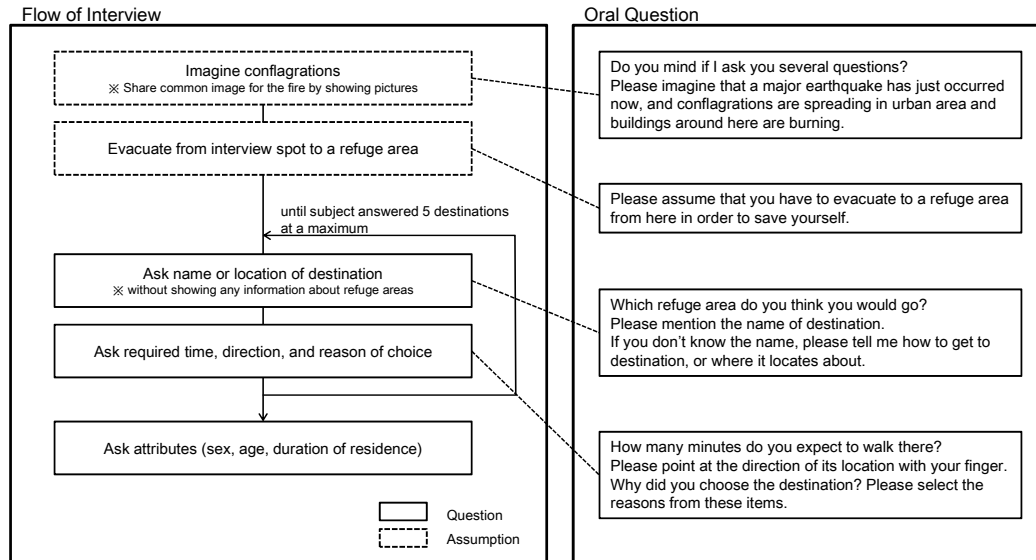

Fig. 2. Flow of interview and orally-asked questions.

Results and Discussion

The answers obtained by the interview survey were analyzed and the factors governing the recognition degree were identified. If the required time or the direction answered by a subject had large error even though he answered the name of the refuge area correctly, it was deemed that the subject did not recognize the refuge area correctly.

Contribution Degree by Duration of Residence

The subjects were classified in terms of duration of residence as shown in Table 3, where duration of residence was categorized into Six levels: (a) within 1 year; (b) within 1 to 5 years; (c) within 5 to 10 years; (d) within 10 to 20 years; (e) within 20 to 40 years; and (f) within more than 40 years. The value in parenthesis in Table 3 corresponds to the proportion to the total number at each level (rightmost column). The number of the subjects who could not answer any refuge areas correctly was 1,209, which amounts to 53% of the total number of the subjects. On the other hand, the number of the subjects who could answer at least one refuge area correctly was 1,058. However, note that most of the subjects could recognize only one refuge area. The proportion of the subjects who could not answer any refuge areas correctly was the highest at the levels (a) within 1 year and (b) within 1 to 5 years. The proportion decreased with increase in duration of residence, though the influence of duration of residence was not remarkable.

Table 3. Breakdown of subjects according to duration of residence.

Duration of residence	Number of recognized refuge areas					Total
	0	**1**	**2**	**3**	**4–**	
–1 year	123 (0.62)	61 (0.31)	13 (0.07)	0 (0.00)	0 (0.00)	197 (1.00)
1–5 years	248 (0.63)	122 (0.31)	17 (0.04)	6 (0.02)	1 (0.00)	394 (1.00)
5–10 years	116 (0.54)	77 (0.36)	20 (0.09)	2 (0.01)	0 (0.00)	215 (1.00)
10–20 years	149 (0.56)	99 (0.37)	16 (0.06)	2 (0.01)	0 (0.00)	266 (1.00)
20–40 years	258 (0.51)	210 (0.41)	40 (0.08)	1 (0.00)	0 (0.00)	509 (1.00)
40 years–	315 (0.46)	290 (0.42)	68 (0.10)	13 (0.02)	0 (0.00)	686 (1.00)
total	1,209 (0.53)	859 (0.38)	174 (0.08)	24 (0.01)	1 (0.00)	2267 (1.00)

Asymmetry of Recognition Sphere

The top 10 refuge areas which obtained the most answers are shown in Fig. 3. Imperial Palace Park of Kyoto was the most, followed by Nijo Castle, Umekoji Park and Kyoto University Ground. All the top 10 refuge areas are located in the area bounded by Higasiyama Mountain, Uji River and Katura River. Among the refuge areas, Imperial Palace Park of Kyoto was selected as study refuge area and recognition sphere of it was analyzed.
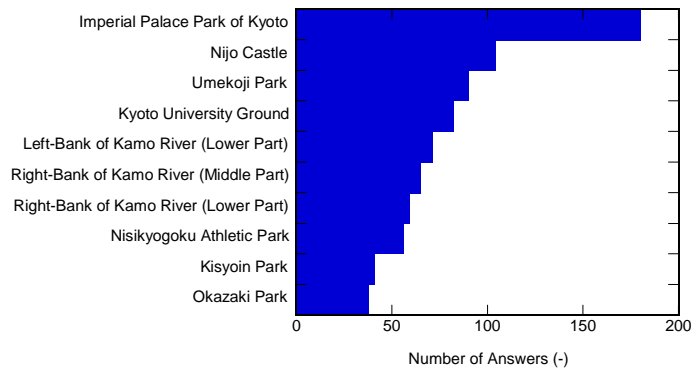

Fig. 3. Top 10 refuge areas of number of answers.

The proportion of the subjects who named Imperial Palace Park of Kyoto at each interview spot is shown in Fig. 4, where the size of the circles corresponds to the proportion. The proportion was higher as an interview spot is closer to Imperial Palace Park of Kyoto. The proportion basically decreased with increase in distance even though the values varied depending on direction. In Fig. 4, the proportion at the interview spots along Marutamati St. (dotted line A) and Imadegawa St. (dotted line B) are also illustrated by line-graphs, which run east-to-west tangent to southern and northern edge of Imperial Palace Park of Kyoto. Focusing on the interview spots along Marutamati St. and Imadegawa St., the subjects who named Imperial Palace Park of Kyoto were concentrated on the west side of Kamo River which runs north-to-south between Kawaramati St. and Kawabata St., and decreased suddenly at the spots across the river to the east. It is conceivable that geographical gap, such as river which lies between a refuge area and a resident, induces some psychological resistance and affect the choice of the refuge area. Almost all of the subjects who named Imperial Palace Park of Kyoto were distributed in the area within 2km from the refuge area. However there were a small number of exceptions which still named despite of larger distance to the refuge area. The contributing factors of this are as follows: (1) Imperial Palace Park of Kyoto is included in the range of living activities of the subjects; and (2) recognition sphere of Imperial Palace Park of Kyoto as evacuation destination is much broad.
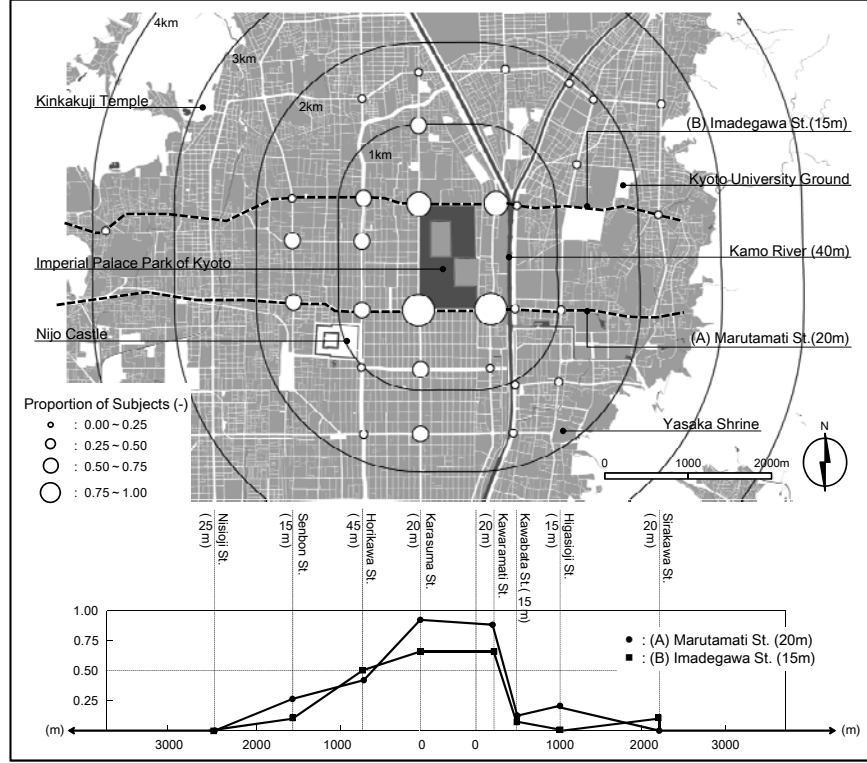
Fig. 4. Spatial distribution of subjects who named Imperial Palace Park of Kyoto.

MODEL FOR RECOGNITION DEGREE OF REFUGE AREAS BY RESIDENTS

The schematic of the recognition model of refuge areas by Kyoto City residents is shown in Fig. 5. In the model, the probability that a refuge area is recognized as evacuation destination by a resident in post-earthquake fire situation P_R (the recognition probability) is defined.

Recognition Probability

Formulating the recognition probability P_R, the following hypothetical quantities were assumed: (A) potential of a refuge area Φ; and (B) threshold of a resident Θ. As the potential of a refuge area Φ exceeds the threshold of a resident Θ, the refuge area is assumed to be recognized as evacuation destination by the resident:

$$\Phi \geq \Theta \tag{1}$$

where the potential Φ and the threshold Θ are the random variables. The potential Φ corresponds to the hypothetical value for mathematically formulating the decision structure of evacuation destination, and the larger the value of the potential Φ, the easier the refuge area is recognized. In the model, the potential Φ is assumed to be the specific value of each refuge area and is expressed as follows:

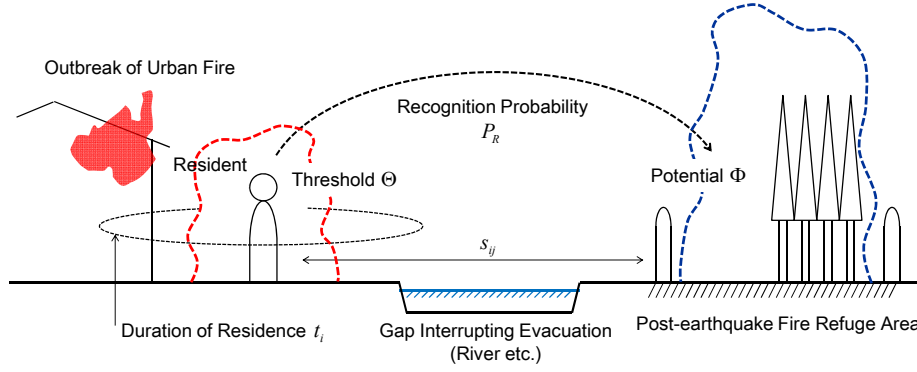$$\Phi_j = \overline{\Phi}_j + \Phi'_j \tag{2}$$

Fig. 5. Schematic of recognition model of refuge areas by residents.

where j is the identification mark of a refuge area, $\overline{\Phi}_j$ is the non-fluctuation component of the potential, and Φ'_j is the fluctuation component of the potential. On the other hand, the threshold Θ is assumed to be determined by the relation between a refuge area and a resident and is expressed as follows:

$$\Theta_{ij} = \overline{\Theta}_{ij} + \Theta'_{ij} \tag{3}$$

where i is the identification mark of a resident, $\overline{\Theta}_{ij}$ is the non-fluctuation component of the threshold, and Θ'_{ij} is the fluctuation component of the threshold. In the model, the non-fluctuation component of the threshold $\overline{\Theta}_{ij}$ is expressed as a liner function of the governing factors obtained from the above discussion:

$$\overline{\Theta}_{ij} = \alpha_1 \cdot t_i + \alpha_2 \cdot s_{ij} + \alpha_3 \cdot d_{ij} + \alpha_4 \tag{4}$$

where α_1, α_2, α_3, α_4 are constant, t is the duration of residence (year), s is the direct distance between a refuge area and initial location of a resident (m), and d is the dummy variable whose value is 1 if there is a gap interrupting evacuation between a refuge area and a resident, otherwise 0.

The recognition probability P_R is given as follows from Eq. 1:

$$P_R = \mathrm{P}\left(\Phi_j \geq \Theta_{ij}\right) = \mathrm{P}\left(\Theta'_{ij} - \Phi'_j \leq \overline{\Phi}_j - \overline{\Theta}_{ij}\right) = F\left(\overline{\Phi}_j - \overline{\Theta}_{ij}\right) \tag{5}$$

where $\mathrm{P}(A)$ is the probability that event A arises, and F is the cumulative distribution function of $\Theta'_{ij} - \Phi'_j$. In the model, the fluctuation components Φ'_j and Θ'_{ij} are assumed to independently vary according to Gumbel distribution. The cumulative distribution function of random variable X according to Gumbel distribution $F(x)$ is expressed as follows:

$$F(x) = \exp\left[-\exp\left(-\frac{x-a}{b}\right)\right] \tag{6}$$

where a and b are constant. When independent random variables X_1 and X_2 are according to Gumbel distribution where a is equal to 0 and b is equal to 1, the cumulative distribution function of $X_2 - X_1$ is known to be given as follows:

$$\mathrm{P}(X_2 - X_1 \leq x) = \frac{1}{1 + \exp(-x)} \tag{7}$$

Thus the recognition probability P_R expressed by Eq. 5 is rewritten as follows:

$$P_R = \mathrm{P}\left(\Theta'_{ij} - \Phi'_j \le \overline{\Phi}_j - \overline{\Theta}_{ij}\right) = \frac{1}{1 + \exp\left[-(\overline{\Phi}_j - \overline{\Theta}_{ij})\right]} \tag{8}$$

Validation of Recognition Model

The unknown parameters included in Eq. 8 were estimated by using the survey data, i.e., (1) the non-fluctuation components of the potential $\left(\overline{\Phi}_1, \overline{\Phi}_2, \cdots, \overline{\Phi}_N\right)$; and (2) the constants regarding the threshold $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$. Estimating the parameters, maximum-likelihood method and regression model were used simultaneously. In maximum-likelihood method, unknown parameters are calculated by solving the following equation with Newton method:

$$\frac{\partial \log L(\boldsymbol{\beta})}{\partial \boldsymbol{\beta}} = 0 \tag{9}$$

where $\boldsymbol{\beta}$ is the matrix of unknown parameters, and L is the likelihood function. The function L is defined as the probability that the data observed by the survey arises simultaneously and is expressed as follows:

$$L = \prod_{i=1}^{M}\left(\prod_{k=1}^{N_i}(P_R) \prod_{l=1}^{N_R - N_i}(1 - P_R)\right) \tag{10}$$

where i is the identification mark of a subject, M (= 2,267) is the number of the subjects, N_i is the number of the refuge areas recognized as evacuation destination by a subject i, and N_R is the number of the refuge areas whose potentials are estimated by maximum-likelihood method.

In this analysis, N_R was set as 31 refuge areas which were answered correctly by more than 5 subjects. As to the rest of the refuge areas (= 36), the non-fluctuation components of the potential were predicted by using the regression model developed based on the estimated results by maximum-likelihood method. The gaps interrupting evacuation were set by the rivers, railways and mountains of more than 40m width.

Estimated Results of Potential

The estimated values of the potential by maximum-likelihood method are shown in Fig. 6, where the refuge areas were classified into five categories: (a) park; (b) school; (c) river; (d) historical space; and (e) other. Note that the potential is relative index so that the value may be either positive or negative. Approximate curves for each category were obtained as follows:

$$\overline{\Phi}_j = \begin{cases} -1.107 + 1.294\log(S) & (R = 0.727) & \cdots\text{Park} \\ -5.466 + 5.056\log(S) & (R = 0.581) & \cdots\text{School} \\ -0.337 + 0.614\log(S) & (R = 0.438) & \cdots\text{River} \\ -1.043 + 1.061\log(S) & (R = 0.785) & \cdots\text{Historical - space} \\ -1.419 + 0.731\log(S) & (R = 0.911) & \cdots\text{Other} \end{cases} \tag{11}$$

where S is the site area of a refuge area (ha), and R is the correlation coefficient. As a result, the estimated values of the potential were positively correlated with the site area S. However there was poor correlation between both variables for refuge areas categorized in "river".
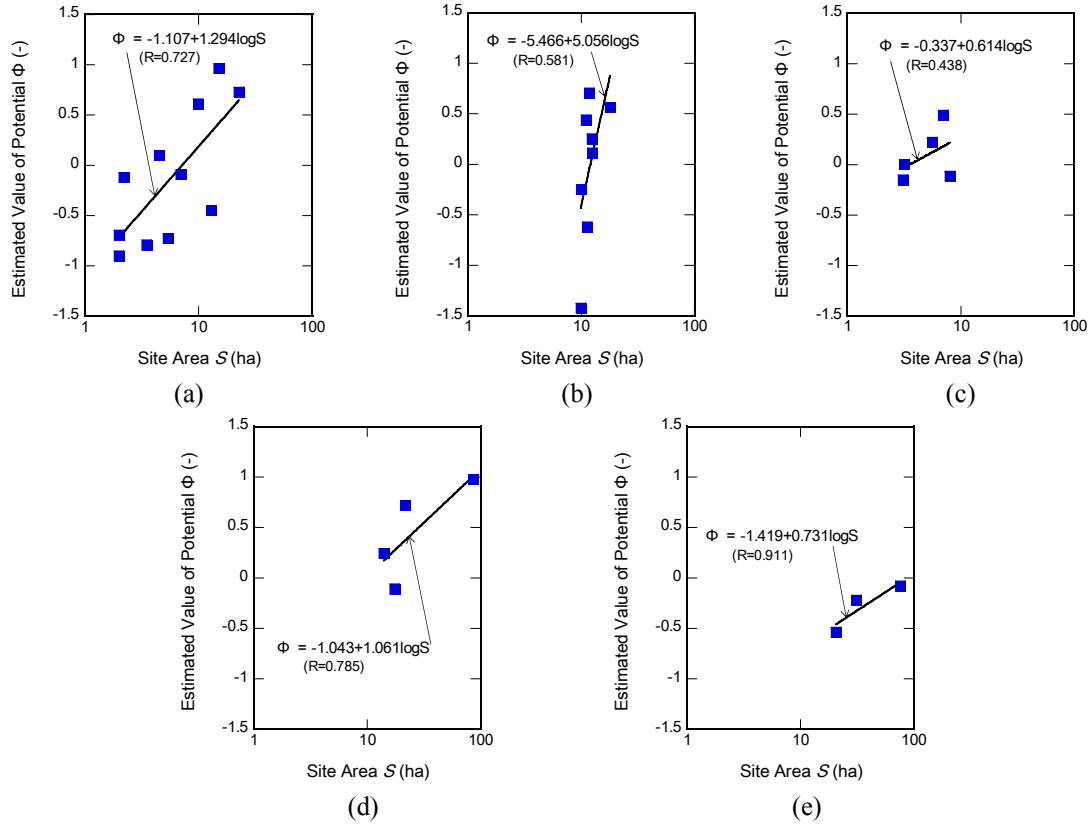
Fig. 6. Estimated values of potential by maximum-likelihood method: (a) park; (b) school; (c) river; (d) historical space; (e) other.

The estimated values of the potential for all the refuge areas are listed in Table 4, and visualized in Fig. 7. In Fig. 7, the height of the bars corresponds to the estimated values of the potential. The potential was estimated to be the highest for Imperial Palace Park of Kyoto, followed by Nisikyogoku Atheltic Park, Takaragaike Park, Umekoji Park, Nijo Castle and Kyoto University Ground. Especially the values of the potential of Imperial Palace Park of Kyoto and Nijo Castle are high because they are the important touristic/cultural symbols of Kyoto City. Such high-potential refuge areas concentrate in the central area of Kyoto as shown in Fig. 7. So in post-earthquake fire, many residents in this area may recognize evacuation destination at high probability. However, it is concerned that a large number of evacuees may concentrate on a single refuge area depending on fire spread condition. Thus, the refuge area may not be able to accommodate all of the evacuees. On the other hand, in the western area where high-potential refuge areas are rare, many residents may wander around in urban area without recognizing evacuation destination. So it will be required that some organizations such as firefighters and police officers guide the residents to neighboring refuge areas in post-earthquake fire situation.
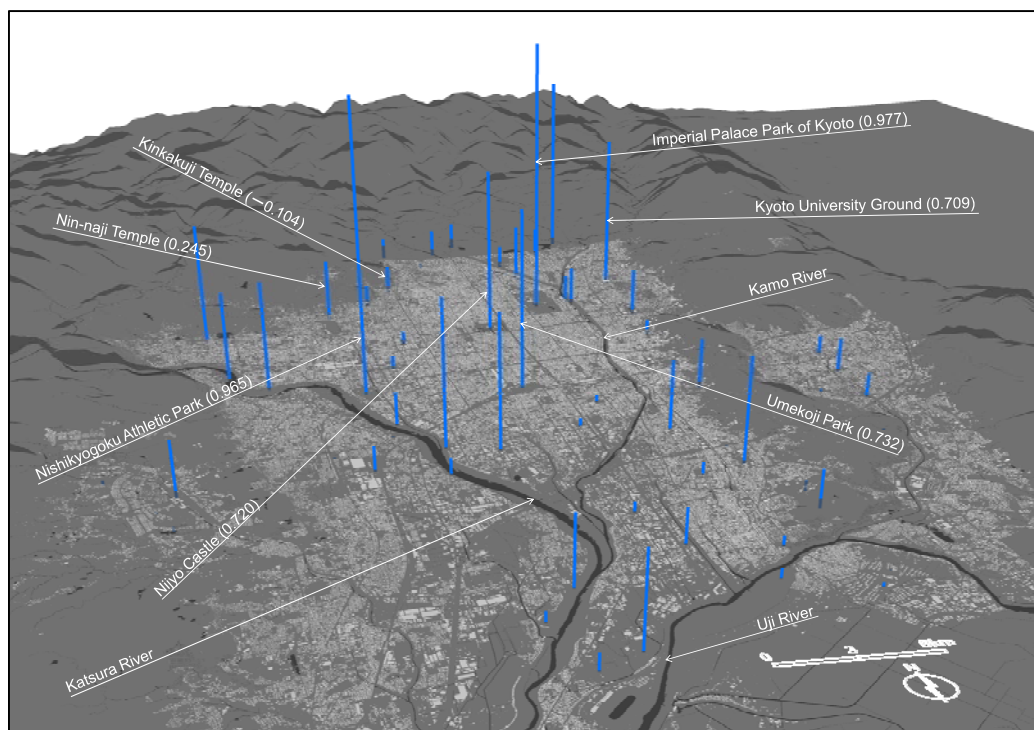
Fig. 7. Spatial distribution of estimated values of potential of refuge areas in Kyoto City.

Table 4. List of estimated values of potential of refuge areas in Kyoto City.

Name of post-earthquake fire refuge area	Class	Site area (ha)	Estimated value of potential (-)
Imperial palace park of Kyoto	historical	87.0	0.9772
Nisikyogoku athletic park	park	15.0	0.9652
Takaragaike park	park	30.0	0.8044
Umekoji park	park	22.7	0.7324
Nijo castle	historical	21.8	0.7196
Kyoto university ground	school	11.8	0.7085
Kisyoin park	park	9.9	0.6137
Tonan high school ground	school	1.4	0.5731
Bukkyo university ground	school	18.0	0.5637
Left-bank of Katura river (middle part)	river	7.0	0.4936
Kyoto university of education	school	11.0	0.4436
Right-bank of Katura river (upper part)	river	15.5	0.3939
Yokooji athletic park	park	13.0	0.3344
Kyoto police school ground	school	12.4	0.2527
Ninnaji temple	historical	14.0	0.2454
Right-bank of Kamo river (middle part)	river	5.6	0.2224
Hadukasi athletic park	park	10.4	0.2090
Obatagawa central park	park	9.0	0.1278
Hiyosigaoka high school ground	school	12.5	0.1132
Okazaki park	park	4.5	0.0972
Left-bank of Kamo river (lower part)	river	3.2	0.0060
Higasino park	park	6.3	-0.0727
Momoyama imperial mausoleum	other	76.0	-0.0788
Takaragaike sports space	park	7.0	-0.0908

Table 4 (continued). List of estimated values of potential of refuge areas in Kyoto City.

Name of post-earthquake fire refuge area	Class	Site area (ha)	Estimated value of potential (-)
Kinkakuji temple	historical	17.5	-0.1036
Left-bank of Katura river (lower part)	river	8.0	-0.1144
Right-bank of Kamo river (upper part)	river	2.3	-0.1208
Misu park	park	2.2	-0.1208
Golf cource of Kyoto-Kamigamo	other	55.6	-0.1434
Right-bank of Kamo river (lower part)	river	3.1	-0.1489
Kyoto botanical garden	other	31.2	-0.2179
Golf cource of Kyoto-Nisikamo	other	40.0	-0.2479
Ritumeikan university ground	school	10.0	-0.2486
Katura garrison	other	37.4	-0.2692
Kansyuji park	park	4.4	-0.2744
Yamasina central park	park	4.0	-0.3279
Maruyama park	park	13.0	-0.4497
Kuzebasi western park	park	3.1	-0.4712
Kyoto racetrack	other	18.0	-0.5014
Shimadzu corporation ground	other	20.5	-0.5337
Saiin park	park	2.6	-0.5700
Fire academy ground	school	11.3	-0.6150
Husimi park	park	2.0	-0.6894
Mukaijima-south elementary school ground	school	8.7	-0.7158
Simotoba park	park	2.0	-0.7175
Kyoto driving license examination ground	other	8.9	-0.7250
Husimi-Kitahori park	park	5.4	-0.7276
Tonoda park	park	3.5	-0.7872
Kamitoba park	park	1.7	-0.8088
Omiya traffic park	park	2.0	-0.8977
Takenosato elementary school ground	school	7.3	-1.1010
Kyoto city university of arts	school	7.2	-1.1313
Mukaijima junior high school ground	school	7.0	-1.1932
Rakuto driving school	other	1.7	-1.2505
Hino outdoor center	other	1.6	-1.2698
Hukakusa junior high school ground	school	9.9	-1.4231
Ryukoku university ground	school	6.0	-1.5317
Rakusei junior high school ground	school	6.0	-1.5317
Katurasaka elementary school ground	school	5.9	-1.5686
Katura high school ground	school	5.4	-1.7630
Mukaijima-Hujinoki elementary school ground	school	5.0	-1.9320
Katuragawa junior high school ground	school	4.8	-2.0216
Ogurisu junior high school ground	school	3.5	-2.7152
Rituryo junior high school ground	school	3.2	-2.9120
Kasugaoka junior high school ground	school	3.2	-2.9120
Higasiyama high school ground	school	3.0	-3.0537
Rakusei junior high school ground	school	1.5	-4.5757

Estimated Results of Threshold

The constants regarding the threshold $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$ were estimated as follows:

$$\left.\begin{array}{l} \alpha_1 = -5.851 \times 10^{-3} \\ \alpha_2 = 2.325 \times 10^{-3} \\ \alpha_3 = 0.717 \\ \alpha_4 = -0.132 \end{array}\right\} \tag{12}$$

The constant regarding the duration of residence α_1 was estimated to be negative. This implies that the longer the living time in urban area, the lower the threshold Θ (the higher the recognition probability P_R). The constant regarding the direct distance between a refuge area and initial location of a resident α_2 was estimated to be positive, i.e., increase of the distance s elevates the threshold Θ (reduces the recognition probability P_R). The constant regarding the gap interrupting evacuation α_3 was estimated to be positive, so the gap is thought to induce some psychological resistance and affect the choice of the refuge area.

CONCLUSION

In this study, recognition degree of refuge areas by Kyoto City residents in post-earthquake fire situation was modeled by introducing new concepts: potential of a refuge area Φ and threshold of a resident Θ, which are the hypothetical quantities to mathematically formulate the decision structure of evacuation destination. Firstly, the interview survey was carried out on 2,267 residents in Kyoto City, and the following factors were identified as the governing factors of recognition degree of refuge areas: (1) duration of residence; (2) direct distance between a refuge area and a resident; and (3) geographical gap interrupting evacuation. Then, recognition degree of refuge areas was formulated considering the factors and the model was validated by using the survey data.

The potential Φ and the threshold Θ could be quantified though sufficient validation of the values is difficult, so that it became possible to predict evacuation destination of a resident considering bias of recognition degree of refuge areas by using the parameters estimated in this paper. Following this study, the present model for city evacuation [1–2] will be refined by incorporating the recognition model developed in this paper. It is expected that the refined model will be able to predict the evacuation behavior more reasonably and become an effective tool for evaluation of evacuation safety measures.

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