A STUDY OF EVACUATION BEHAVIOR DURING EARTHQUAKES

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ABSTRACT
Earthquakes are a hazard in Taiwan and elsewhere. In 1946, for example, a Richter scale 6.1 earthquake caused 556 causalities and damaged more than 4,000 buildings in Sin-hua, Tainan City, Taiwan. This study investigates the aspects of resident preferences with respect to earthquake shelters. A questionnaire survey was designed to reflect the viewpoints of respondents in the context of earthquakes, including: (1) factors affecting evacuation behavior, (2) historical street district damage prevention and (3) analysis of evacuation choices. A logistic model for evacuation behavior in major earthquakes is presented, and its significant variables discussed in the context of future urban disaster planning.
Keywords: Evacuation behavior, *logistic regression model*, *shelter.*

1 INTRODUCTION
In 1999, Taiwan's 921 earthquake showed the vulnerability of urban areas to disaster. The unpredictable earthquake hazard requires the establishment of a prior comprehensive disaster plan, followed by a reactive posterior rescue plan for the maximization of resident and property safety. Recent research literature is focused on the institutional and statutory dimensions, in general, rather than a disaster, context. Although residents' viewpoints (public participation) are included in the decision-making process, most studies have focused on the location of obnoxious facilities. Evacuation shelter planning is considered from the supply side.

The present study aims at reflecting the viewpoints of residents using questionnaires and tries to find out: (1) the key factors affecting the behaviors of evacuation, (2) the shelters choices made by residents, (3) mechanisms of damage limitation in the historic street district, and (4) a logistic model of resident choice. Finally, the significant factors of the evacuation behavior are considered in the context of urban planning. This paper is organized into five sections. First, an introduction briefly points out the motives and objectives. Secondly, the literature is reviewed. Thirdly, the method and content of the questionnaires is explained. Fourthly, the results are analyzed and discussed, and finally, conclusions are drawn.

2 LITERATURE REVIEW
In consideration of the evacuation behavior, Kates [1] found that evacuation to shelters was hampered, to varying degrees, due to earthquake damage to buildings, bridges and roads destroyed after quakes. Løvås [2] discusses a variety of evacuation route selection criteria that may be applied by earthquake survivors. Lindell and Whitney [3] examined the relationships of self-reported adoption of 12 seismic hazard adjustments (pre-impact actions to reduce danger to persons and property) with respondents' demographic characteristics, perceived risk, perceived hazard knowledge, perceived protection responsibility, and perceived attributes of the hazard adjustments. Russo and Vitetta [4] research for the analysis and modeling of transportation systems in emergency conditions requires further studies in supply, demand, supply–demand interaction and design. In emergency conditions, there is the need to develop new methods and rearrange standard procedures.

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Kimura *et al.* [5] considered the evacuation behavior and found that following shocks over 6.7 on the Richter scale, 30% people decided to evacuate to designated shelters. Lee *et al.* [6] applying Logistic Regression Model found that evacuation transportation planning, education level and residence years significantly influence the evacuation decision of residents. Tai *et al.* [7] explained four possible actions relating to the spatial decision concerning disaster prevention. (i) Shelters help reduce risks and meet evacuation needs. (ii) And (iii) Disaster prevention provides an efficient way to meet both requirements. (iv) Providing disaster prevention information can remind people about disaster preparedness. Anastassiadis and Argyroudis [8] urban vulnerability assessment of elements at risk is performed through a value analysis approach based on appropriate indicators such as population, residential and trade densities, radiance and others, while a pilot application is made for Thessaloniki. The vulnerability of road network is also examined based on the interaction between collapse patterns of adjacent buildings and network functionality.

Ayis *et al.* [9] selected 999 people over 65 for a study of the mobility of the aged and found lower mobility and poor perceived health. Mobility was significantly (and negatively) related to age, over 70. Yi and Őzadmar [10] pointed out that logistic, and especially route planning, was critical for earthquake contingency planning. Ho *et al.* [11] findings are: (1) the victims and the general public are concerned about the different potential hazards that might affect their residential area, (2) the negative associations between the sense of controllability and the perceived impact is high for landslide victims, but not for flood victims, and (3) disaster type, gender, and previously experienced disasters are good predictors of victims' attitudes toward natural disasters.

In a review of empirical work, Perry [12] suggested that individuals assessed personal risk by examining the proximity, certainty, and severity of the threat. In general, shelter choice was related to distance from the victims residences. Chien *et al.* [13] found most people first selected schools, then parks, and green field locations. However, factors influencing evacuation were numerous, including physical environmental characteristics, familiarity, accessibility, habit, and safety considerations. This study reviews the factors influencing evacuation and applies a questionnaire to determine their perceived relative importance for the purpose of evacuation modeling.

3 METHOD

The questionnaire is divided into three parts: (1) factors effecting evacuation of residents; (2) evaluation of historic street district; and (3) evacuation intentions. An objective evaluation equation based on binary logistic regression is used to model the evacuation behavior of residents.

3.1 Logistic regression model

James and Johnson [14] applied a Logistic Regression Model to evacuation from near a nuclear power plant and found the probability of an individual evacuating is related to distance from the power plant, age, perceived risks to the household, and the perceived safety of the power plant. Socioeconomic variables were insignificant. Riad *et al.* [15] found that previous experience or training in evacuation procedures was the most significantly related to evacuation, followed by gender, perceived risk, home ownership, income, education, children, the actions of neighbors, and previous disaster experience.

Assuming residents' decision to evacuate is a conditional probability $P\left(y=1 \middle| x_{\mathrm{i}}\right)=p_i$. Equation (1) gives the probability that residents will evacuate, and eqn (2) the probability that they will not. Equation (3) represents the ratio of eqns (1) and (2). Equation (4) is the natural log of eqn (3), i.e. logit type of the results.

$$p_i = \frac{1}{1+e^{-(\alpha+\beta x_i)}} = \frac{e^{\alpha+\beta x_i}}{1+e^{\alpha+\beta x_i}} \quad (1)$$

$$1-p_i = 1-\left\{\frac{e^{\alpha+\beta x_i}}{1+e^{\alpha+\beta x_i}}\right\} = \frac{1}{1+e^{\alpha+\beta x_i}} \quad (2)$$

$$\frac{p_i}{1-p_i} = e^{(\alpha+\beta x_i)} \quad (3)$$

$$ln\left[\frac{p_i}{1-p_i}\right] = \alpha+\beta x_i \quad (4)$$

where p_i is the probability of residents' evacuation, x_i the independent variables, all variables affecting the evacuation behavior, α the intercept, β the regression coefficients and e the residuals.

3.2 Questionnaire surveying

At the end of May 2006, there were 10 wards in Sin-hua urban planning area with 23,330 residents in 7,298 households. Equation (5) was used for samples of 385 under 95% confidence interval.

$$n = p(1-p)\times\left(Z/E\right)^2 \quad (5)$$

where n is the sample size, p the ratio of samples, Z the 95% confidence interval and E the maximal error tolerance.

The field survey was conducted in September 14–18, 2006. Trained interviewers visited each ward using a random sampling regime of an intensity determined by the relative population density of the wards. Four hundred questionnaires were issued, with 387 effective samples (excluding 13 with conflicting missing or undecided responses). Field sampling involved starting from a street corner and walking in an anti-clockwise direction, knocking on doors asking for interview, and repeating until the necessary sample size was obtained.

4 RESULTS

4.1 Descriptive statistic results

4.1.1 Social–economic analysis

The social–economic descriptive analysis results are shown in Table 1 and are summarized below:

1. The ratio of male to female was 4:6: 41.9% male (162) and 58.1% female (225).
2. 70.6% (22.5% + 27.4% + 20.7%) of the samples were between 21 and 50, with only 15.7% over 51 (11.6% + 2.8% + 1.3%). Most of the respondents were young adults.
3. 43.7% (169) of the samples were high school, and 34.6% (134), college graduates. In general, the respondents were educated and could receive information from news.
4. The households were divided into those (1) with children age <12, (2) with elders age >65, (3) both of (1) and (2), and (4) other. Groups (1), (2), and (3) are identified as vulnerable in evacuations. 64.8% (28.7% + 18.3% + 17.8%) of households were in this group, and the special requirements of such households should be allowed for evacuation planning.

Table 1: Social–economic description.

Items	Variables	Samples	%	Items	Variables	Samples	%
Gender	Male	162	41.9	Education	Elementary	23	5.9
	Female	225	58.1		Junior high	53	13.7
Age	<20	53	13.7		Senior high	169	43.7
	21~30	87	22.5		College	134	34.6
	31~40	106	27.4		Graduate	8	2.1
	41~50	80	20.7	Household	<12[1]	111	28.7
	51~60	45	11.6		>65[2]	71	18.3
	61~70	11	2.8		Both of 1 and 2	69	17.8
	>71	5	1.3		Other	136	35.2

Table 2: Residents decide NOT to evacuate.

Reasons	Samples	%	Reasons	Samples	%
Nowhere to go	45	11.7	Safer to stay than leave	148	38.2
Without vehicles	9	2.3	No idea but stay in house	55	14.2
Difficult links outside	8	2.1	Dangers for moving	60	15.5
Living inconvenience	48	12.4	Others	14	3.6

4.1.2 Factors affecting evacuation

Considering the factors affecting residents decide Not to evacuate, Table 2 shows the highest ratio (38.2%) appeared in ‘Safer to stay than leave’. The basic idea is that the home forms the base for living. In case of danger, people would rather to stay put. However, outside the house the uncertainty of the environment after the disaster would deter the residents from remaining in the house.

Secondly, ‘Danger for movement’ showed the unpredictable outcome after hazard people rationally consider the situation to make a good choice between stay or to leave. In general, we found some people think the instantaneous event of earthquake and react naturally without advance considerations.

Considering the factors affecting the potential decision of residents to evacuate, Table 3 shows the most important reason appeared as ‘House collapsed’. ‘Road link collapsed’ showed the lowest rating. It represented the uncertainty of the transportation conditions and, therefore, had an ambivalent or negative influence on resident’s decision to evacuate.

Of the Preferred choices for shelter, referred in Table 4, the most important was ‘Nearest house’. It was clear that residents preferred to evacuate to locations as close as possible to their houses. The lowest important item was ‘Enough lighting services’ in the night. It appeared people would easily survive without lighting compared with other services.

4.1.3 Shelter choice

The result in Table 5 for shelter choice by residents depicted ‘School’ 49.4% where there were open spaces of greens and fields, and the classroom and activity center could offer temporary accommodation after a quake. However, constructional resilience of the classroom and resistance to earthquakes was required for the construction due to the public safety.

Table 3: Residents decide to evacuate from normal location.

Reasons	Samples	Average	Order	Standard deviation
House collapsed	387	4.00	1	1.18
Road links collapsed	387	2.15	4	1.12
Damage and danger on site	387	3.19	2	1.19
Building services collapsed and not functioning	387	2.28	3	1.21

Average represents the Likert 5-point scale. 5 meant the strongest intention.

Table 4: Preferred choices for shelter.

Reasons	Samples	Average	Order	Standard deviation
Nearest house	387	3.60	1	1.12
Familiarity of the surroundings	387	3.54	2	1.19
Enough lighting services	387	2.32	4	1.21
Convenient living facilities	387	3.27	3	1.45

Average represents the Likert 5-point scale. 5 meant the strongest intention.

Table 5: Shelters choice by residents.

Items	Samples	%	Items	Samples	%
School	191	49.4	Green field	92	23.3
Park	53	13.7	Parking lot	17	4.4
Sports field	34	8.8	Amount	387	100.0

Parks and green fields comprised 37% (13.7% + 23.3%) of choices due to the selection of open spaces for evacuation. However, in the 1980 periodic review of urban plan, 10.25 hectares of parkland and 0.11 hectares of green fields were rezoned for residential use with additional permissions when developed with public services supplied (see Fig. 1). Suitable areas for evacuation shelters were therefore in short supply due to residential development.

4.1.4 Historic street district evaluation

When we asked about the importance of historic street conservation, people concerned about the potential risk of the quake attack and endangerment of historic asset.

Table 6 shows 59.2% (14.2% + 45%) people (non-residents) are very concerned about the possibility of serious damage. The historic street with a Baroque architectural style was constructed in the Japanese colonial era (1925). It had been a historical landmark and common memory. However, the vulnerable structures were not safe in an earthquake and could danger life. 10.1% (8.3% + 1.8%) non-residents expressed less concern about the fate of the street.

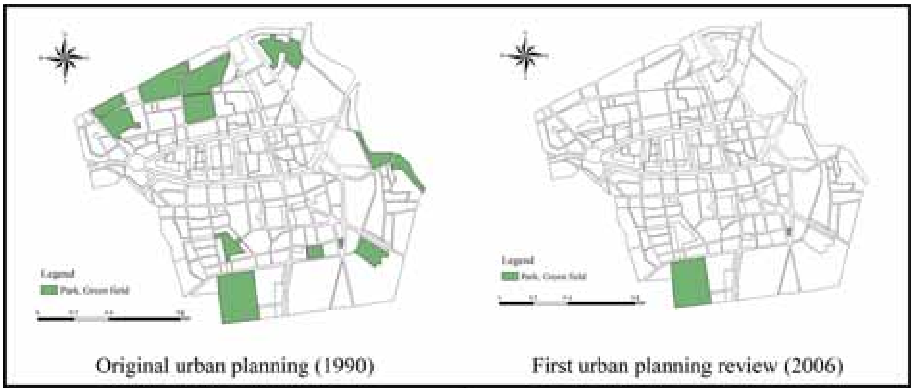

Figure 1: Park and green field location diagram.

Table 6: Concern about potential destruction of the historic street district by earthquake.

Items – level of concern	Samples	%
Very concerned	55	14.2
Concerned	174	45.0
Medium concern	119	30.7
Less concern	32	8.3
Not concerned	7	1.8
Amount	387	100.0

Table 7: Support for rebuilding historic street for the safety of residents.

Items	Samples	%
Strongly agree	73	18.9
Agree	169	43.6
Neither agree nor disagree	90	23.3
Disagree	40	10.3
Strongly disagree	15	3.9
Amount	387	100.0

In the following, the results of Table 7 represent resident attitudes about the idea of rebuilding the street to be earthquake resistant. There were 62.5% (18.9% + 43.6%) of residents strongly supporting rebuilding this street to reflect concern about the safety of life and property. However, there were also 14.2% (10.3% + 3.9%) who disagreed and strongly disagreed considering this cultural asset and the meaning of this historic development for the next generation.

In Table 8, 60.4% (19.1% + 41.3%) agreed with the widening road width of historic street district disaster for prevention. The main reason reflected the serious possibility that the 4-m width would

Table 8: Widen road width in historic street district for disaster prevention.

Items	Samples	%
Agree very much	74	19.1
Agree	160	41.3
Neither agree nor disagree	97	25.1
Disagree	51	13.2
Disagree very much	5	1.3
Amount	387	100.0

Table 9: Evacuation intention of residents.

	Scale	Samples	%	Analogy to Likert scale	%
Low	1	25	6.5	Very low	8.6
	2	8	2.1		
	3	22	5.7	Low	11.4
	4	22	5.7		
Intention	5	67	17.3	Medium	28.4
	6	43	11.1		
	7	46	11.9	High	27.1
	8	59	15.2		
High	9	14	3.6	Very high	24.5
	10	81	20.9		

result in lane blockage after a quake. However, there were 14.5% (13.2% + 1.3%) who disagreed due to the historic asset preservation considerations, and the complexity of the land ownership.

4.1.5 Intention of residents to evacuate

It had been more than 50 years since the 1946 earthquake. Most of the interview subjects did not have Richter scale more than 7.0 earthquake evacuation experiences. Therefore, the questionnaire design assumed an imaginary scenario comparable to the 921 earthquake (2494 fatalities, 105,480 buildings collapsed). The results in Table 9 show 51.6% (27.1% + 24.5%) respondents expressed strong intention to evacuate. 20% (8.6% + 11.4%) had low and very low intention to evacuate. Disaster experiences were highly related to evacuation intention.

Next, the location of those subjects (8.6% + 11.4%) who showed low and very low intention to evacuate was displayed (▲) using Arc GIS 10 overlayered with the location of those subject groups classified as vulnerable during evacuation (•). Figure 2 shows the overlap of ▲ and •. Most of the respondents with intention to evacuate were co-located with evacuation–vulnerable groups. The results represented the subject's intuitive response to the dangers of earthquakes and the risks of evacuation. When facing an unexpected hazard, people were apparently very influenced by the difficulty of movement with the aged and children, and might give it more weight than unknown dangers.

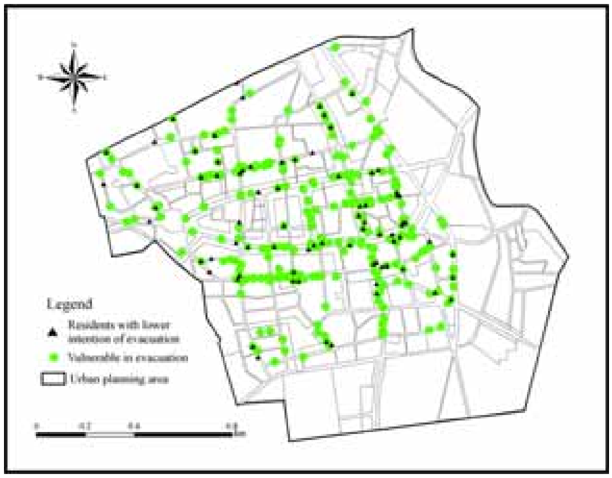

Figure 2: Overlapping of low evacuation intention and evacuation weakness.

4.2 Logistic regression model of evacuation

4.2.1 Variable selection

4.2.1.1 *Dependent variable*

To predict evacuation choice behavior K means clustering was applied and the samples were categorized as evacuation intention high and low. The two categories of evacuation intention were used as the dependent variables for the choice model.

4.2.1.2 *Factors affecting resident's evacuation choice*

a. House collapsed (X_1): after a quake serious damage to the house will push people to evacuate. The expected sign is '+'.
b. Road link collapsed (X_2): after a quake serious damage to road links will push people to evacuate. The expected sign is '+'.
c. Damage and danger on site (X_3): after a quake serious damage and danger on site will push people to evacuate. The expected sign is '+'.
d. Utilities not functioning (X_4): after a quake serious failure of utilities will push people to evacuate. The expected sign is '+'.

4.2.1.3 *Affecting factors of shelters' choices*

a. Familiarity of the surroundings (X_5): after a quake, familiarity of the shelter surroundings will pull people to evacuate. The expected sign is '+'.
b. Convenient living facilities (X_6): after a quake, convenient living facilities will pull people to evacuate. The expected sign is '+'.

4.2.2 Estimation of the model

This study used the maximum likelihood method, HL index and precision rate to evaluate model fitness. In addition, the Wald Chi-square test was used with odds to explain significant variable results.

4.2.2.1 *Coefficient estimation*
The results of Wald estimation showed that variables X_1, X_2, X_3, X_4, and X_6 significant.

4.2.2.2 *Model estimation*
Table 10 explains the model estimation results. Maximum likelihood (−2LL) was 90.084, Cox & Snell R^2 was 67.8%; the model explained 67.8% of the observed variation. The HL index was 7.177 and significance was 0.518 (>0.05). The regression results could explain the dependent variable and the predicted probability was 95.9%.

4.2.2.3 *Significant variables*

a. House collapsed (X_1)
The result coefficient was 4.925 > 0, significant in 99% confidence interval with expected sign. This variable explained more serious of the house collapsed and residents would express higher intention to evacuate. Moreover, the model showed house collapsed residents intention to evacuate 137 times than not in terms of odd ratio.

b. Road link collapsed (X_2)
The result coefficient was 4.836 > 0, significant in 99% confidence interval with expected sign. This variable explained more serious of the road link collapsed and residents would express higher intention to evacuate. Moreover, the model showed house collapsed residents intention to evacuate 125 times than not in terms of odd ratio.

c. Damaged and danger on site (X_3)
The result coefficient was 5.878 > 0, significant in 99% confidence interval with expected sign. This variable explained more serious of damaged and danger on site and residents would express higher intention to evacuate. Moreover, the model showed house collapsed residents intention to evacuate 356 times than not in terms of odd ratio.

d. Utilities not functioning (X_4)
The result coefficient was 4.567 > 0, significant in 99% confidence interval with expected sign. This variable explained more serious of life line collapsed and not functioning and residents

Table 10: Logistic regressing analysis results.

Independent variables	*B*	SE	Wald	*p*	Odds
House collapsed (X_1)	4.925	0.774	40.436	0.000*	137.671
Road link collapsed (X_2)	4.836	0.777	38.769	0.000*	125.908
Damage and danger on site (X_3)	5.878	0.879	44.734	0.000*	356.975
Building services collapsed and not functioning (X_4)	4.567	0.730	39.171	0.000*	96.213
Familiarity of the surroundings (X_5)	–0.142	0.286	0.248	0.618	0.867
Convenient living facilities (X_6)	–1.104	0.311	12.643	0.000*	0.331
Constant (*a*)	55.841	8.566	42.500	0.000*	0.000
−2 Log-likelihood (−2LL): 90.084.					
Cox and Snell R^2: 0.678					
HL index estimate: 7.177, degree of freedom: 8, significance: 0.518					
Predicted probability (%): 95.9					

*99% significant level.

would express higher intention to evacuate. Moreover, the model showed house collapsed residents intention to evacuate 96 times than not in terms of odd ratio.

e. Convenient living facilities (X_6)
The result coefficient was −1.104 < 0, 99% confidence interval with an unexpected sign. More convenient living facilities were associated with a lower expressed intention to evacuate. The result was not expected. Convenient living facilities are apparently not critical for residents to evacuate, but the facilities must still be adequate for people to stay temporarily.

4.2.2.4 *Insignificant variables*

Familiarity of the surroundings (X_5) showed a coefficient of −0.142 < 0, insignificant at the 99% confidence interval with an unexpected sign. A possible reason was residents could not decide if the shelter was familiar or not. After an earthquake conditions became abnormal. In such a time of uncertainty, a lack of information may prevent people from taking many criteria, including this one, into consideration.

The Logistic Regression Model results could explain the dependent variable and the predicted probability was 95.9%. Additional analysis results showed that X_1, X_2, X_3, X_4 and X_6 significantly affect the choice of evacuation. 'House collapsed' promoted evacuation. 'Road link collapsed' represented uncertain transportation conditions and difficulty for residents to make decision. 'Damage and danger on site' and 'Utilities not functioning' both promoted evacuation, while 'Convenient living facilities' in shelters showed that such facilities were necessary and aid to the evacuees but not critical in terms of survival.

5 CONCLUSIONS

The behavior and choices of urban residents must be an important component in urban disaster planning, which aims to secure life and property. Faced with an unexpected natural or human hazard, past disaster experiences could give a basis for planning rules. We found that there were about 64.8% household with (1) children aged <12, (2) elders age >65 and (3) both of (1) and (2). These groups would be vulnerable and difficult to evacuate during a disaster. As populations age, there disaster planning will have to accommodate more aged people with lower personal mobility.

Finally, logistic regression choice model showed that X_1, X_2, X_3, X_4 and X_6 had significant effect on evacuation decisions. The variables in terms of house collapsed, road link collapsed, damage and danger on site, building services collapsed and not functioning should be seriously considered in contingency planning for the aftermath of an earthquake. However, convenient living facilities were not considered important by residents. Most people regard earthquake disaster as a low probability event, and tend not to think about it, which can increase the unpredictability of the impact. Further study is therefore urged to promote resident and community empowerment for disaster preparedness. A localized plan could limit the initial disaster impact and reduce the damage.

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