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Research Article

TRAVEL DEMAND BEHAVIORAL MODEL AFTER DISASTER (EARTHQUAKE) IN TEHRAN, IRAN

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ABSTRACT

Based on high risk of earthquake occurring in Tehran, the issue of post-earthquake travel demand needs to be investigated. The aim of this study is to determine the trip purposes immediately after the earthquake and the factors affecting the individuals' decisions on their trip purposes. The effective factors on the traffic behavior of individuals are analyzed under 4 earthquake scenarios (powerful, moderate, day and night) by two multinomial logit models, for day and night separately, based on stated preference surveys. The post-earthquake traveling is defined with 4 purposes of relief and rescue, return-to-home, immediate evacuation and nothing for the day earthquake, and 3 purposes of inquiry on safety, immediate evacuation and nothing for the night earthquake. The survey data indicated that, 90% of people may prefer to make trips in order to return to home or to rescue survivals after a powerful day earthquake. The results indicated that having children and the time interval are the most important factors affecting the trip purposes. Furthermore, education (unrelated to the earthquake) doesn't have any effect on the post-earthquake behavior of the individuals. Increasing the awareness of the individuals about the post-earthquake trips and usable routes after the earthquake will contribute to the disaster management schemes.
Keywords: Traffic behavior, multinomial logit model, post-earthquake travel demand, earthquake, disaster management, travel behavior.

1. INTRODUCTION

Probability of a magnitude 6 to 7 (Richter) earthquake occurring in Tehran is high due to the presence of surrounding active faults [1]. Since unusual demand is created on a partly destroyed network after an earthquake, major traffic problems are even seen in the intact sections of the transport network [2]. Also a disaster may cause changes in the traffic behavior of transport network users [3]. Investigating the issue of post-earthquake travel demand seems to be necessary due to the specific effects of the earthquake on the travel demand (i.e. the influx of travel demand in a short period and chaotic behavior of the users of the transport network) [4]. In most previous

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literatures, the majority of policies which have been modeled are based on unrealistic assumed demand. For example, Since an earthquake cannot be predicted, in a study conducted by Chang et al. to estimate the post-earthquake travel demand, it is assumed that people will evacuate directly from their current locations immediately after earthquakes because under the no-notice earthquake scenarios, there is no time or considerably less time for people to return home or go to other places to pick up their relatives or friends [5]. While most people will return to home to rescue their family [6]. Some other researchers have also taken advantage of the pre-earthquake travel demand for the post-earthquake planning and have attempted the management strategies after modifying it [5] [7]. However, it should be noted that the pre-earthquake travel demand is not appropriate to assess the post-earthquake performance of the transport network.

In order to calculate the post-earthquake changes in the traffic patterns, the post-earthquake performance of the transport network should be evaluated. In order to analyze and predict the post-earthquake travel demand, it is first necessary to evaluate the behavior of individuals in an earthquake disaster. In the present study, the trip purposes are determined and the factors affecting the individuals' decision on their trip purposes are investigated. In this regard, in a study conducted in Tokyo, the post-earthquake trip purposes are classified into six purposes including immediate evacuation (within 48 hours), relief and rescue, inquiry on safety, evacuation for temporal stay, acquisition of food and clothes and checking up offices and schools. The share of each trip purpose is determined within 2 weeks after the disaster to estimate the post-earthquake travel demand. A high travel demand is created due to the trips made on returning to home, but the survey doesn't include this trip purpose [8]. As mentioned above, most of the studies are conducted on the basis of assumptions about the post-earthquake behavior of individuals that may be far from reality and may not be available in all countries or be only used for the sake of simplicity. This study is conducted with the goal of contributing decision-makers toward the disaster management to estimate the travel demand immediately after the earthquake disaster. The data were collected according to a survey of people working in zone 10 of Tehran in which the respondents were asked about their post-earthquake trip purposes, trip specifications and socioeconomic status under four earthquake scenarios (day, night, powerful and moderate).

In this study, the multinomial logit model has been used in order to determine the post-earthquake trip purposes and the factors contributing to each of them.

2. LITERATURE REVIEW

In the past decades, many researchers have studied the factors affecting individuals' decisions on their trip purposes and travel demand for various disasters. They have presented various behavioral models in this regard [9] [10]. Since the earthquake is not predictable and the post-earthquake travel demand encounters the reducing capacity of transport network due to the destruction of structures, the post-earthquake behavior of the individuals is different from the other disasters [5]. In another study conducted in China, the most influential factors in the decision of individuals on evacuating the area after the earthquake are the type of building (house or apartment), house ownership, the individuals past experiences of the disaster (sustaining damage or not), mandatory evacuation order, distance from the location of the incident and the affected areas (less than 1 mile or more), age, marital status [11]. Those who have received education related to the disaster were already prepared for the disaster situations; whether receiving a high unrelated education (Ph.D.) doesn't have any effect on their behavior [12]. In another study, it was noted that in the event of an earthquake occurring on the day, parents will return to home to save their children first and later decide to leave the area together. Gender, car ownership and travel distance (from where the parents are to where the children are) were the main factors affecting the individuals' traffic behavior [13]. Walton et al. conducted a study on the individuals' traffic behavior after two earthquake scenarios (powerful and moderate) and reported that the trips are not only to return to home but also have been made with other purposes as well

[14]. On the whole, in the previous studies, a set of socioeconomic status, mandatory evacuation orders and the trip characteristics have been identified as affected factors on the post-earthquake trips. In the present study, it has been attempted to investigate a combination of factors affecting the possible post-earthquake trips.

3. METHODOLOGY

3.1. Earthquake Scenario

According to JICA, Ray fault is the strongest and north of Tehran fault comes after that. In the event of activation of these faults, earthquakes of magnitude 7 and 5.5 on the Richter scale will respectively occur in the south of Tehran and they have been considered as the earthquake scenarios in this study. Since the time of an earthquake (day or night, working or non-working day) has also a substantial effect on the post-earthquake behavior of the individuals and where they would go after the earthquake occurrence, the hypothetical earthquake scenario should also consider time of earthquake occurrence in order to model the travel demand [5]. Therefore, 4 earthquake scenarios including an earthquake that occurs on the day (day earthquake), an earthquake that occurs at the night (night earthquake), a moderate earthquake and a powerful earthquake have been considered in this study. It is assumed that day earthquake occurs in the morning of a working day that all employees are at work and the schools are open. Considering this situation, the most critical state will happen to the traffic in the transport network. Another earthquake is assumed to occur at midnight while people are asleep in their homes (Such as the Bam earthquake, 2003). In addition, the damages caused by the moderate and the powerful earthquakes are estimated [1].

1) Specifications of the earthquake of magnitude 5.5 (moderate): minor damage (up 10%) to the typical buildings made with bricks and metal or the buildings over the age of 30 (type B). Damages (up to 40%) to weak and badly designed brick buildings (type C) including cracks and falling plaster walls and ceiling. There would not be a severe damage to the lifelines and the phone would be usable [1].

2) Specifications of an earthquake of magnitude 7 (powerful): well-designed structures (type A) would be bent and their location on the Foundation would be displaced. Type (c) structures would destroy and type (B) buildings would be heavily damaged (up to 85%) or completely destroyed. The streets with the widths less than 6 meters would be closed. Some roadway bridges would be damaged. Telephone, water, gas and electricity would be cut off. There would be the probability of fire and explosion at gas stations after the earthquake [1].

3.2. Data Acquisition

The survey was conducted in such a way that the individuals were interviewed face to face due to the requirement to explain the situation to them. In this regard, 364 individuals were asked to fill in the questionnaire designed with the stated preference (SP) methods. In the first part of the questionnaire, the individuals were asked questions about the type of their building (structure of the building and its age) in order to specify the extent of damage against the moderate and powerful earthquakes. In the second part, explaining earthquake scenarios and damages caused by them, the individuals were asked about their first post-earthquake trip purposes. The trips made after the day earthquake are defined with 4 purposes as follows:

A. Relief and rescue: trips on relief/rescue as well as trips to confirm the safety of the family members, like looking forwards children at schools or other family members out of home.

B. Return-to-home: trips from work to home.

C. Immediate evacuation: trips in order to leave the place where the individual at the time of the earthquake is and to go to a safe place (i.e. the nearest park or outdoor space to work/home appointed by the disaster management organization).

D. No travel: individuals who do not make a trip.

The post-earthquake trips for the night earthquake are defined with 3 purposes as follows:

A. Inquiry on safety: checking up offices. Since there is a possibility of looting shops and offices after the earthquake, many individuals prefer to make a trip to their shops or work and collect their valuable property.

B. Immediate evacuation: trips in order to leave the place where the individual at the time of the earthquake is and to go to a safe place (i.e. the nearest park or outdoor space to work/home or somewhere out of town).

C. No travel: staying at home.

In the third part of the questionnaire, the individuals were asked about their personal characteristics such as age, gender, marital status, having children, education and past experiences of the disaster, and their economic characteristics such as size of their family, the number of their private vehicles, the vehicle used to go to work under normal conditions and house/apartment ownership. The data were collected according to a survey of people working in zone 10 of Tehran in which 52% of streets have a width less than 6 meters and wouldn't be accessible after the earthquake occurrence [1]. According to the JICA studies, this zone may sustain the most severe damages in terms of human casualties and destruction of buildings. Therefore, it is considered as the study area in this research. Since the way in which individuals make decisions when they are at work was concerned, the interviews were conducted while they were at work. The individuals considered in this study were employees, teachers and shopkeepers (all of whom owned shops).

3.3. Descriptive Statistics

Table 1 gives an overview of all Descriptive statistics. 77% of people in the statistical sample own a car, but only half of them go to work with their cars. About 20% of people in the statistical sample have had past experience of a powerful earthquake and none of them selected the choice "no travel" in the questionnaire.

Table 1. The statistical characteristics of the collected data

Variable	Average	Standard deviation
Gender (male=1, female=0)	0.52	0.501
Age	36.11	10.111
Marital status (single=0, married=1)	0.71	0.456
Education (High school diploma=0, Diploma=1, BS/BA/BE =2, MS/MA/ME=3, Ph.D./Doctor=4)	1.86	0.781
Having a child who goes to school (Yes=1, No=0)	0.55	0.499
Family size	3.28	0.98
Job (employee)=0, self-employment=1)	0.18	0.382
Car ownership (Yes=1, No=0)	0.77	0.419
Car ownership at work (Yes=1, No=0)	0.42	0.495
House/apartment ownership (Yes=1, No=0)	0.68	0.467
Past experience of a powerful earthquake (Yes=1, No=0)	0.19	0.395
stability of the building (Good (groups A and B) = 1, weak (group C) = 0)	0.74	0.438
the time interval from work to home (min)	28.57	23.287
the time interval from work to school (min)	29.54	22.831

3.4. Logit Model

In this study, the multinomial logit model was used to analyze the acquired data. This model is capable of designating the share of each trip purpose and also factors affecting the selection of any of the trip purposes. The general form of the multinomial logit model is given in equation (1) [15].

$$P_n(i) = \frac{e^{U_{in}}}{\sum_{j \epsilon C} e^{U_{jn}}} \quad (1)$$

U_{in}: The utility of alternative i for the person n, $U_{jn:}$ The utility of alternative j for the person n, $P_n(i)$: The probability of choosing i for the person n from C possible alternatives. In order to build the discrete choice logit models, the maximum likelihood method shown in equation (2) is used.

$$LL(\beta) = \sum_n \sum_{i \epsilon C} \left(y_{in} ln\left(P_n(i)\right)\right) \quad (2)$$

LL (β): Log-likelihood function after building the model; y_{in}=1, if the individual n chooses i; y_{in}=0, if the individual n doesn't choose i [15]. The goodness of model fit measure (ρ^2 statistic) is used to validate the model that is calculated as follows:

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} \quad (3)$$

$$\rho_c{}^2 = 1 - \frac{LL(\beta)}{LL(c)} \quad (4)$$

LL(0): Log-likelihood function assuming all parameters set to zero.
LL(β): Log-likelihood function after building the model; LL(c): The value of the log-likelihood functions for every constant term.

4. MODELING

The variables used in the post-earthquake trip model along with a brief explanation of them are given in Table 2. The variables were defined in different ways according to the requirements in order not to ignore the various effects caused by the changes in the variables. For instance, the variable for the age was defined as several dummy variables for the individuals under the age of 30, in the age range of 20 to 40 and 40 to 50, and over the age of 50. In order to modeling, the variables correlated with the dependent variable were identified using the correlation test and then taking advantage of the software NLogit 4.0, The β coefficients were obtained for the final model to determine the contribution of each of the post-earthquake trip purposes as well as identifying the factors influential in any of the trip purposes.

The travel time variable in the model, for trips from home to the rescue places (e.g. schools) and for trips from work to home is equal to the time interval (in minutes) required to make this trips. For trips to the safe place, if the individuals choose a place close to where they are, it is equal to 10 minutes and if they choose somewhere out of town, it is equal to 2 hours. For those who prefer not to make a trip, it is equal to 0.

Table 2. The variables used in the multinomial logit model for the post-earthquake trip purposes

Independent variable	Variable Coding
Details about the trip:	
travel time*	In minutes
Having a private car at work	Yes: 1, No: 0
Details about the earthquake:	
Earthquake magnitude	Powerful: 1, weak: 0
Having a previous experience of a powerful earthquake	Yes: 1, No: 0
stability of the building	fortified: 1, weak: 0
Socioeconomic status:	
Gender	Female: 0, male: 1
Age group 1 (years)	20 to 30: 1, other: 0
Age group 2 (years)	30 to 40: 1, other: 0
Age group 3 (years)	40 to 50: 1, other: 0
Age group 4 (years)	More than 50:1, other: 0
marital status	Single: 0, Married: 1
Education	Diploma: 0, Upper: 1
Job	Employee: 0, self-employment (shop ownership): 1
Parents of school children	Yes: 1, No: 0
House/apartment ownership	Yes: 1, No: 0
Family size	Number

5. RESULTS AND DISCUSSION

5.1. Day Earthquake

Statistical analysis of the trip purposes, based on the magnitude of the earthquake, showed that after occurring the powerful earthquake, 23% of the individuals will make trips on relief/rescue, 68% of them will return to home and the others will make trips to the safe places. After the moderate earthquake, 10% of the individuals will make trips on relief/rescue, 24% of them will return to home, 12% will make trips to the safe places and the others will stay where they are. Table 3 gives an overview of the results of the multinomial logit model for the post-earthquake trip selection. The dependent variable in the model is the trip purpose after an earthquake on a working day. In order to perform the analysis and build the model, in addition to the previously defined variables, different composition variables were used, some of which improved the model. The ρ^2 statistic for the model was obtained 0.425 that is a fairly good indicator for the discrete choice models. The model has also predicted the trip purposes in 67% of the observations correctly.

The parents*gender combined variable is obtained negative, indicating that mothers are more willing to provide relief which confirms the results obtained by [13]. The results also showed that parents are more likely to provide relief and it corresponds with the results obtained by [11]. If the earthquake occurred is powerful, people will be more willing to choose a relief trip due to a sense of danger. Comparing the coefficient of the variable for the earthquake magnitude in relief/rescue and return-to-home utility functions, it is found that after powerful earthquake, the individuals are more willing to provide relief and then return to home. In such situation, they wouldn't tend to have an immediate evacuation or stay where they are, immediately after the earthquake. Since the individuals who have a stable house/apartment wouldn't feel a need to check up their homes, they are more likely to provide relief. However, the individuals who own a house/apartment prefer to

return to home and check up their property and valuable things. The negative coefficient of travel time variable indicates that the longer the travel time, the weaker the individuals' tendency to provide relief, which confirms the result obtained by [13]. The coefficient of the variable is small due to the travel time in minutes in this model and the time interval being in the range of 3 to 120 minutes (large numbers). The results indicate that as the family size is greater, the individuals are more willing to return to home and not to go to a safe place first, after the earthquake. Men who are over the age 50 are more willing to go to a safe place than the women of the same age, after the earthquake. This demonstrates the impact of gender on trip purposes and points to the fact that the gender variable affects the post-earthquake trip purposes. Since individuals make decisions with respect to the sense of danger as well as their information on the earthquake, the education variable has no effect on decision making. According to the conducted interviews, only a small number of the individuals (6 individual) had received a high education (MSc and Ph.D.) in the field of earthquake and they were the only ones who had developed a plan for their family to come together in a predetermined location after the earthquake. The location was easily accessible and close to all family members. Since the number of these people was small, it has not affected the model. The variable for the previous experience of a powerful earthquake has not been significant in the model. This could be due to the small number of respondents who have experienced a powerful earthquake. However, none of them have chosen to make no trip. Since the individuals believe that using cars in the critical situation is impossible due to the damages to the streets, having a private car at work had also no impact on the behavior of the individuals.

Table 3. Results of the multinomial logit model of the trip selection for the day earthquake

Trip purposes	Variable	coefficient	P-value
Relief and rescue	Gender * having children	-3.1041	0.0000
	Marital status* having children	5.9301	0.0000
	stability of the house	1.4921	0.0114
	Travel time	-0.0264	0.0256
	Magnitude of the earthquake	4.2188	0.0000
Return-to-home	Constant coefficient	3.5857	0.0002
	Magnitude of the earthquake	3.4206	0.0000
	Family size	0.3524	0.0219
Immediate evacuation and going to a safe place	Constant coefficient	6.0758	0.0000
	Family size	-0.4643	0.0657
	House/apartment ownership	-0.7725	0.0669
	Age over 50* Gender	2.4314	0.0002
No travel	Constant coefficient	5.3853	0.0000
LL(0)	-463.02086		
LL(c)	-415.0472		
LL(β)	-266.3161		
ρ^2	0.425		
ρ^2_c	0.358		
Accuracy of the estimation (%)	%67		

5.2. Earthquake Occurring at the Night

Statistical analysis of the trip purposes, based on the magnitude of the earthquake, indicated that after the powerful earthquake, 10% of the individuals will make trips to check up offices and 88% will make trips to the safe places. After the moderate earthquake, 46% of the individuals will have an immediate evacuation and 52% prefer to stay at their homes. According to the acquired

data, more than half of the individuals whose first trip after the earthquake are to have an immediate evacuation, prefer to seek refuge in a safe place out of the city. Therefore, a large number of the individuals tend to leave the city after the earthquake which may lead to a heavy traffic on the roads leading to the city outlets. Table 3 indicates the results of the multinomial logit model. The dependent variable in the model is the trip purpose after the earthquake at the night. The fitness index (ρ^2 statistic) of the model was obtained 0.572 that is a fairly good indicator for the discrete choice models. The model has also predicted the trip purposes in 73% of the observations correctly.

Table 4. Results of the multinomial logit model of the trip purpose for the night earthquake

Trip purposes	Variable	coefficient	P-value
Inquiry on safety	Gender * Job	3.5338	0.0001
	Gender * Age over 50	0.0501	-1.6912
	Gender * travel time	-0.0478	0.0851
	Earthquake magnitude	6.1756	0.0000
Immediate evacuation	Constant coefficient	4.8685	0.0002
	Gender * Job	-1.0014	0.0365
	Earthquake magnitude	4.5517	0.0000
No travel	Constant coefficient	3.0351	0.0076
	Family size	0.3870	0.0184
	Stability of the building	0.7329	0.0508
LL(0)	-336.9357		
LL(c)	-255.3770		
LL(β)	-157.2732		
ρ^2	0.572		
ρ^2_c	0.389		
Accuracy of the estimation (%)	%73		

The model results show that men who own a shop are more likely to check up their shops and properties after the earthquake while the individuals who have a government job (employees), as well as men over the age 50, prefer to go to a safe place. The negative coefficient of travel time*gender variable for inquiry on safety trips represents that if the work is far from the home, the individuals show less tendency to chuck up offices and prefer to make a trip on relief/rescue as well as trips to confirm the safety of relatives and acquaintances or have an immediate evacuation. The variable for the gender being significant for the inquiry on safety choice (in the questionnaire) is due to the importance of job and property for men owing to their greater sense of responsibility toward financing the family. At the event of a powerful earthquake, the individuals would be more inclined to check up the shops and there would be also a great desire to have an immediate evacuation. The individuals who are confident of stability of their buildings prefer to stay at their homes due to less sense of danger. However, since the coefficient obtained for the magnitude of the earthquake is high, it is clear that staying at home will be only chosen by the individuals after a moderate earthquake. The modeling results indicate that as the size of the family is greater, the individuals are more likely to stay at home with their families. The variable for the previous experience of a powerful earthquake was also evaluated in the model that slightly improved the model, but the level of significance of this variable was not acceptable. Therefore, it is not included in the model. This could be due to the fact that a few individuals interviewed had previous experience of a powerful earthquake. Providing a more comprehensive statistical sample, this variable may be significant and influential in the individuals' traffic behavior.

6. CONCLUSION

Most previous researches in the field of post-earthquake travel demand have either taken advantage of pre-earthquake travel demand for the post-earthquake planning or simplifying the post-earthquake travel demand based on some assumptions. Multinomial logit model has been used for determining the post-earthquake trip purposes. As stated before, there are 4 main trip purposes immediately after the day earthquake including relief and rescue, return-to-home, immediate evacuation and no trip. In the event of the powerful earthquake occurring in the morning of a working day, 90% of the individuals prefer to make trips to confirm the safety of their family members or return to home first. However, in the previous studies, this trip purpose has been given less attention and most of them have assumed that the individuals' first choice is to have an immediate evacuation [5], which may be due to different behavioral characteristics of individuals in different countries. Since there is a strong emotional tie among the family members in Iran, the individuals prefer to return to home or make trips on relief and rescue first. The results have also indicated that in the event of a moderate earthquake, about 35% of the individuals will make trips on relief and rescue or return to home. It should be noted that a moderate earthquake may not cause much damage to the vital arteries, but the influx of population into the streets due to the sense of danger could lead to traffic congestion in the transport network. The multinomial logit model obtained in this study indicate that having a child as well as the time interval from home to work are the factors that affect the trip purpose made on relief and rescue. If the school is close to work, the traffic jam caused by trips on relief and rescue will be lowered due to the possibility to walk to the school. If the school is close to home, the number of trips will be reduced as well.

The collected data indicated that, while a powerful earthquake occurs at the night, 90% of the individuals might prefer to have an immediate evacuation and take refuge in a safe place. This figure is about 35% for a moderate earthquake occurring at the night. More than half of the individuals whose first trip after the earthquake is to have an immediate evacuation, prefer to take refuge in a safe place out of the city. Therefore, a large number of cars tend to leave the city after the earthquake which may lead to a heavy traffic on the roads leading to the outlets. The model results have also shown that men who own a shop are more likely to check up their shops indicating that there would be many trips to the shopping centers after the earthquake.

The modeling results indicated that the unrelated education doesn't have any effect on the individuals' post-earthquake behavior and only those with sufficient information on earthquake have already prepared for such situations and they have developed a plan for their family to come together in a predetermined location after the earthquake. Regarding the travel time from work to home and no cars available at work (42% of the individuals in this study) or useless streets after the earthquake it is suggested to inform people about the post-earthquake accessible public transportation or usable routes in advance. A model could be provided to predict the trip generation in different routes in Tehran after the earthquake, conducting a comprehensive survey on different individuals in different zones of Tehran. The model could be built based on the worn out textures, population density, the amount of available outdoor spaces etc. for each zone in the city.

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