Urban Disaster Prevention Shelter Location and Evacuation Behavior Analysis

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Abstract

This study proposes a simple method of analyzing the road network factors and evacuation choices of residents in case of an earthquake. Using questionnaire survey data from Shin-Hua, Tainan County Taiwan, this study uses 6 indexes to evaluate shelter safety and applies a spatial statistic model with Local Indicators of Spatial Association (LISA) as an index to the evacuation choice of residents. Firstly, factor analysis is used to find the key factors affecting shelter safety, and cluster analysis is used to classify attributes. The final results with quantified indexes are then depicted in GIS maps for urban planning.

Keywords: urban safety; shelter; evacuation choice; spatial autocorrelation; Geographic Information System

1. Introduction

In 1999, the 921 Great Earthquake revealed Taiwan's lack of a comprehensive disaster prevention mechanism in urban development. After this incident, it became clear that urban planning should review disaster prevention. However, most plans consider institutional and practical factors, and are less concerned about the needs of residents. After an earthquake, many areas may be isolated due to the collapse of buildings and blocked roads. Fortunately, urban safety is now regarded as a critical issue in urban development. Therefore, it is important to plan suitable locations for earthquake shelters to allow safe evacuation of residents after a disaster.

Shelters play an important role after quakes. However, urban planning often emphasizes the supply of facilities more than the demand of residents. This is especially true when disasters strike in abnormal hours, when most of a city's functions are reduced. Therefore residents' needs should be the main consideration of disaster prevention. This study first reviews the most likely causes of shelter vulnerability in terms of road networks. Then, six evaluation indexes are selected and a case study is proposed to estimate the results. Finally, this study selects Shin-Hua Township located in the south of Taiwan as a case study. Shin-Hua Township is a suitable case study because a 6.1 Richter scale earthquake occurred there in 1946, causing 556 causalities and damaging or destroying, more than 4,000 buildings. Next, this study analyzes survey data for residents and integrates these results into a GIS map using address matching. Then spatial statistics are applied to analyze evacuation behavior in terms of clustering and dispersal. Finally, this study provides some results for policy making.

2. Literature Review

The efficiency of urban road networks may change after an earthquake due to road damage caused by collapsed buildings and blockages. Tsukaguchi and Li (1999) carried out a survey after the Great Hanshin-Awaji Earthquake and applied a discriminate model to verify the causes of road closure. They also developed a simulation model to improve different network structures of road network design. Odani and Uranaka (1999) analyzed traffic conditions immediately after the Great Hanshin-Awaji Earthquake, considering not the only main roads, but also other minor roads that suffered serious damage. Lee and Yeh (2003) surveyed after the 921 Great Earthquake, and found that a street width less than 4 meters was the main reason for road closure after earthquakes in Taiwan. Chen et al. (2002) combined reliability and uncertainty analysis, network equilibrium models, and sensibility analysis of an equilibrium network flow to assess the performance of a degradable road network. Hongo et al. (2006) considered the local characteristics of rich cultural heritage sites in Kyoto, using the road network viewpoint in terms of 10 independent indexes and 3 composite indexes.

In consideration of evacuation behavior, Kates (1971) found that people who evacuated to shelters were hampered to varying degrees due to earthquake
damage to buildings, bridges, and roads destroyed by the quake. Løvås (1998) discussed a variety of evacuation route selection criteria that could be used by earthquake survivors. Kimura et al. (2004) found that 30% of people decided to evacuate to designated shelters after shocks of 6.7 on the Richter scale. Ayis et al. (2006) selected 999 people over the age of 65 for a study on the mobility of the aged. The results of that study indicate that mobility is significantly (and negatively) related to age (over 70). Song (2006) found that evacuations are generally inefficiently conducted in times of disaster. The Cell Automation (CA) method is useful in simulating an evacuation process and interpreting evacuation behavior observations. Yi and Özdamar (2007) pointed out that logistics and route planning are critical for earthquake contingency planning. Perry (1979) suggested that individuals assess their personal risk by examining the proximity, certainty, and severity of the threat. In general, shelter choice is related to distance from the victims residences. Chien et al. (2002) found that most people selected schools first, and then parks and green fields. However, many factors influence evacuation choices, including physical environmental characteristics, familiarity, accessibility, habit, and safety considerations.

Previous studies on evacuation modeling lack spatial analysis. This study attempts to evaluate with a case study using a simple evaluation method and a GIS map, and also uses spatial statistics to analyze evacuation behavior in terms of spatial clusters or dispersal. Finally, GIS mapping shows the spatial autocorrelation of the evacuation intentions of residents.

3. Method

3.1 Shelter safety evaluation

For post-earthquake evacuation, after quake shelters ought to be situated as near as possible to residents, in a safe location without road blockage, and within easy access of rescuers and a fire station. This study modifies and constructs an evaluation index based on previous studies. The following section explains each index:

- $X_1$: shortest emergency route from a residential zone to road width $> 20$ M.
- $X_2$: shortest emergency route from a residential zone to a fire station and road width $> 8$ M.
- $X_3$: shortest emergency route from a residential zone to a police station and road width $> 8$ M.
- $X_4$: shortest emergency route from a residential zone to a shelter (elementary school) and road width $> 8$ M.
- $X_5$: fault line to a 1500M range residential zone in terms of distance intervals (5 intervals, 1 means very few buildings, 5 means many buildings).
- $X_6$: shelters service range and estimated evacuation capacity (age<15, age >65).

Using data collected for the above, this study applies factor analysis to apply for variables reduction including the implicit effects. Next, it uses cluster analysis to combine observations into groups of similar criteria for factor analysis, and finally illustrates integrated results in a GIS map to explain shelter service capacities and evaluation results.

3.2 Spatial analysis of evacuation behavior

(1) Moran's I

Moran’s I analysis is applied to explain the spatial autocorrelation of using Equation (1). This Equation denotes $(i, j)$ as the location in space, $(x_i, x_j)$ as the relative attributes, $(\bar{X})$ as the average of the attributes, and $(W_{ij})$ as the weights (where a higher value means closer distances).

$$I = \frac{n}{\sum_{j=1}^{n} \sum_{i=1}^{n} W_{ij} (x_i - \bar{X})(x_j - \bar{X})} \sum_{j=1}^{n} (x_j - \bar{X})^2, \ i \neq j$$

Fig.1. shows that the results of Moran's I are between -1 and 1. Moran's I=0 indicates a positive relation and Moran's I<0 indicates a negative relation. However, Moran's I=0 indicates a random spatial distribution.

![Fig.1. Spatial Autocorrelation Analysis Diagram](image)

Moran's I=0 (positive relation) Moran's I=0 (negative relation)

(2) Local Indicators of Spatial Autocorrelation (LISA)

 Moran's I describes the comprehensive characteristics of a region. Anselin (1995) proposed the Local Indicators of Spatial Autocorrelation (LISA) approach for spatial autocorrelation statistics based on surveyed points. In Equation (2) $x_i$ denotes the point attributes, $\bar{X}$ is the average of the surveyed points attributes, $x_j$ is the attribute of neighboring point $i$, and $W_{ij}$ is the weights. The estimation results of $L_i$ applying a Z test show the significance of the spatial cluster. Equation (3) classifies these results as hot spots (High-High, $Z>1.96$) and cold spots (Low-Low, $Z<1.96$). Hot spots and cold spots represent spatial clusters and dispersal areas, respectively. However -1.96<Z<1.96 means that the spatial autocorrelation is insignificant. Fig.2. shows the spatial outlier (High-Low or Low-High).

$$L_i = \frac{\sum_{j=1}^{n} W_{ij} (x_j - \bar{X})}{\sum_{j=1}^{n} (x_j - \bar{X})^2}$$

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This study uses Moran’s I to explain the evacuation behaviors of residents, while LISA illustrates the location of hot spots and cold spots. This makes it easy to identify the characteristics of residents’ behaviors as cluster or dispersal. The results of this analysis contribute to contingency planning.

\[ Z = \frac{\text{Moran's } I - E(I)}{\sqrt{\text{Var}(I)}} \]  

(3)

4. Results and Discussion

4.1 Earthquake shelter location analysis

Table 1. shows the factor analysis results (Principal Components Analysis). The data matrix shows the maximum loading factors in two dimensions.

In consideration of variance of the model explanations of factor 1 \((X_1 \sim X_4)\) is 32.150%, and factor 2 \((X_5 \sim X_6)\) is accumulated to account for 59.421% explainable variance. Table 2. shows the results.

Next, this study uses cluster analysis with two factors as external criteria to classify 119 surveyed residential areas as risky and safe. Fig. 3. illustrates the results in a GIS map and shows the following:

1. Shelter S6 is located in a risky area close to the fault line (to the north) and far away from the fire station (located to the south). The northern part of the city is relatively risky.

2. The south-western part is near two shelters (S5 and S4) and has many evacuation weaknesses, making this area relatively risky.

3. The eastern part of the city near Shelter S3 (the junior high school) with many evacuation weaknesses making this area relatively risky.

4. The other safe areas (high school and elementary

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**Table 1. Factor Loading Matrix of Evaluation**

| Variables                                                                 | Factors 1 | Factors 2 |
|---------------------------------------------------------------------------|-----------|-----------|
| shortest emergency route from a residential zone to road width > 20 M, \(X_1\) | 0.681     | -0.493    |
| shortest emergency route from a residential zone to a fire station and road width > 8 M, \(X_2\) | 0.635     | 0.594     |
| shortest emergency route from a residential zone to a police station and road width > 8 M, \(X_3\) | 0.715     | 0.047     |
| shortest emergency route from a residential zone to a shelter (elementary school) and road width > 8 M, \(X_4\) | 0.576     | -0.744    |
| fault line to 1500M range residential zone in terms of distance interval, \(X_5\) | 0.407     | 0.653     |
| shelters service range, and estimated evacuation capacity (age<15, age >65), \(X_6\) | -0.557    | 0.443     |

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**Table 2. Explanation of Factors**

| Factor | Denomination | Eigen value | Accumulation % |
|--------|--------------|-------------|----------------|
| 1      | Road function| 1.929       | 32.150         |
| 2      | Hazard risk  | 1.636       | 59.421         |

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Fig.2. Spatial Cluster Diagram

Fig.3. Earthquake Shelter Location Analysis with Indexes in Shin-Hua Township
school) are located in relatively safe areas because they are closer to a fire station and emergency roads, and are a certain distance away from the fault line.

(5) The visual results provide a quick view of the whole city in terms of safety and risk. The risky area especially requires further survey in the planning stage and temporary evacuation places e.g. green fields, parks or vacant sites should be planned in advance.

4.2 Spatial analysis of evacuation behavior

The questionnaire samples were located using a GIS address matching function. Spatial statistics are then used to analyze the spatial cluster. Finally this study explains and discusses the residents’ evacuation behaviors in terms of spatial clusters or dispersal.

(1) Address Matching

Equation (4) determines the sample size, in which 400 samples were selected in the surveyed area. The field survey was conducted from September 14 through 16, 2006. All the interviewers used a simple random sampling method, and 387 effective samples were collected. An address matching system is then used to locate the samples in the GIS system, as Fig.4 illustrates.

\[ n = p(1-p)(Z/E)^2 \]  

\( n \): sample size.  
\( p \): ratio of samples.  
\( Z \): 95% confidence level.  
\( E \): maximum tolerance value of error.

(2) The spatial autocorrelation of the residents’ evacuation behavior

Fig.5. shows the results of Moran’s I for residents’ evacuation intentions. A result of \( I=0.01 \) means that the spatial autocorrelation is insignificant. However, random distribution cannot be decided yet.

The G-Statistic is then used to show the results in terms of hot spots (clusters of higher evacuation intentions) and cold spots (clusters of lower evacuation intentions) in Fig.6. These G-Statistic results required hypothesis analysis of the Z test. The analysis of \( Z=-2.51<-1.96 \), the random distribution \( H_0 \) assumption is rejected i.e. the residents’ evacuation shows the cold spots (cluster of the lower intention of evacuation).

To find the characteristics of the residents’ evacuation behavior, this study uses LISA to estimate the standard deviation value of \( L_i \). Fig.7. illustrates the attribute value in terms of evacuation intentions. The spot \( \bullet \) represents points of higher autocorrelation, while the spot \( \bigcirc \) represents points of lower autocorrelation. The study area can be divided as 5 places.

For the purpose of clear representation, Fig.8. shows the results of G-Statistic in the 50m range and standard deviation results. There are 3 types concluded as (1) hot spots in solid circle, (2) normal with hidden representation, and (3) cold spots in dashed circle. The results in Fig.9. show that places 1, 3, 4, and 5 represent hot spots (with higher evacuation intentions). Place 2 represents a cold spot (with lower evacuation intentions, see Fig.10.).

In hot spot areas there is one designated shelter located for the convenient access to shelters (place 1, 5). However the nearby and inside Hsin-Hua old street range (place 3, 4) explain the risk recognition of the old structures by the residents. Besides in the cold spot area (place 2) located in a newly built area residents...
showed a lower intention to evacuate and stated that they wished to stay in their house and not to evacuate after a disaster. The main reasons could be that the disaster experiences of the residents were few and the confidence that their house could resist the quake.

4.3 Urban disaster prevention system planning

Shelter planning must consider safety conditions in both normal and abnormal situations. However, Fig.3. shows relatively safe conditions in terms of road network factors. Besides considering the evacuation intentions of residents, this study represents locations of higher and lower evacuation intentions as hot spots and cold spots, respectively. Fig.11. illustrates safe shelter locations and evacuation intention areas together. Further analysis indicates that risky areas show more hot spots (higher evacuation intentions) and safe areas show more cold spots (lower evacuation intentions). Table 3. explains 4 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.

5. Conclusion

Urban safety is the primary concern of urban planning. However, dynamic development has to react based on the results of static planning. This paper proposes a simple process with quick calculation that can be displayed on a GIS map. The results of the 6 selected indexes can be further improved by including architecture structure data and residents' evacuation needs. The visual results of the spatial statistics in
this study can help integrate disaster prevention plans with residents' evacuation behaviors. Moran's I and G-Statistics results show that residents' evacuation intentions are related to spatial factors. With this approach, hot spots (clusters of higher evacuation intentions) and cold spots (clusters of lower evacuation intentions) can be further analyzed in terms of shelter planning. This case study provides the results of cluster and dispersal behavior concerning the residents' evacuation. In particular, this approach allows evacuation weaknesses to be considered in advance.

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Appendix Reference Table of the Shelters

| Shelter | Names               | Shelter | Names               |
|---------|---------------------|---------|---------------------|
| S1      | Shin-Hua Senior High School | S2      | Shin-Hua Elementary School |
| S3      | Shin-Hua Junior High School | S4      | Sport Park          |
| S5      | Jheng-Sin Elementary School | S6      | Da-Shin Elementary School |