Analysis and Modeling of Safety Parameters for Selection of Optimal Routes in Emergency Evacuation after an Earthquake: Case of 13th Aban Neighborhood in Tehran

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Introduction: Earthquakes are imminent threats to urban areas of Iran, especially Tehran. They can cause extensive destructions and lead to heavy casualties. One of the most important aspects of disaster management after earthquake is the rapid transfer of casualties to emergency shelters. To expedite emergency evacuation process the optimal safe path method should be considered. To examine the safety of road networks and to determine the most optimal route at pre-earthquake phase, a series of parameters should be taken into account.

Methods: In this study, we employed a multi-criteria decision-making approach to determine and evaluate the effective safety parameters for selection of optimal routes in emergency evacuation after an earthquake.

Results: The relationship between the parameters was analyzed and the effect of each parameter was listed. A process model was described and a case study was implemented in the 13th Aban neighborhood (Tehran's 20th municipal district). Then, an optimal path to safe places in an emergency evacuation after an earthquake in the 13th Aban neighborhood was selected.

Conclusion: Analytic hierarchy process (AHP), as the main model, was employed. Each parameter of the model was described. Also, the capabilities of GIS software such as layer coverage were used.

Keywords: Earthquake, emergency evacuation, Analytic Hierarchy Process (AHP), crisis management, optimization, 13th Aban neighborhood of Tehran

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Introduction

More than 50 percent of the world population lives in large cities while occupying less that 3 percent the earth. High density of population, assets, infrastructures, and productive and service resources are the causes of metropolitans' vulnerability against the disasters. Natural disasters (especially earthquake) which are mostly hidden and potential for incurring damages threaten all cities worldwide [1]. In a short span of time, earthquake can leave extensive damages and fatalities. What makes a tragedy out of this phenomenon is lack of prevention of its effects and preparation for having proper responses. During the last century, more than one thousands earthquakes have occurred in seventy countries in the world killing more than 1.35 million persons and leaving a huge amount of losses. 80 percent of the damages caused by theses earthquakes belong to six countries one which is Iran. Location of Iran on Alp–Himalaya earthquake belt zone has made earthquake one of the most damaging disasters in Iran, in a way that among the 153 devastating earthquakes occurred in the world, 17.6 percent of them have hit Iran [2]. Such events have always brought about environmental changes and considerable damages. Iranian cities have more or less structural vulnerability, as the statistics show that more than 90 percent of Iranian cities are vulnerable against an earthquake with the magnitude of 5.5 [3]. Among the Iranian cities, the city of Tehran based on the macro-seismic maps is located on the earthquake belt, with 15 dangerous earthquake faults, exposing it more than other cities to the danger of earthquake. Among these faults, the fault of the north of Tehran and the fault of south of Rey have the potential for an earthquake larger than magnitude 7 measured on Richter scale [4].

Tehran has not experienced any powerful earthquake since 1830 [5]. As the statistical studies reveals, it takes a period of 150 years for such a powerful earthquake to reoccur. Considering such a fact, the experts suggest that the occurrence of such powerful earthquake is very likely [6].

Increase of security and safety, decrease of death toll and financial losses of the citizens against the earthquake hazard are among the main aims and measures of the city crisis management. Setting up and optimizing an effective evacuation network with high level of tolerance for emergency evacuation of the devastated area at the shortest possible time are among the vital parts of pre-earthquake phase in crisis management. The metropolitan city of Tehran having more than 700 Sq. M. and the population of more than 8 million (more than 11 million at day) needs a set of predesigned plans and programs for prevention aimed at vulnerability risk reduction and finally an effective crisis management. Cities are prone to natural disasters in different ways most of which (specially the earthquake) cannot be prevented. Therefore, the crisis manager and administrators should devise optimum strategies for evacuation, rescue and support at different areas. For this purpose, safe evacuation routes for emergency evacuation should be identified in the devastated areas and the required measures should be taken for their optimization. Among plans designed for pre-earthquake emergency evacuation in urban areas are identification of city locations, in-the-cities paths and safe areas for emergency accommodation, and most crucially, identification and optimization of the emergency exit paths and registration of these information on the maps to be used by the crisis management headquarter [7 and 8].

Based on its geographical location, construction, faults around the city, history of devastating earthquakes around it, and other technological and geological factors the danger of earthquake in Tehran is high. A glance at the history of Iran earthquakes reveals that the city of Tehran, previously known as Rey, has been devastated many times by earthquake. Despite Tehran's active earthquake zone and registration of many small earthquakes around it, no devastating earthquake has occurred recently, signifying accumulation of energy which can lead to a devastating earthquake [9], while the city safety paths have not been yet established and no safety emergency evacuation network has been identified.

13th Aban neighborhood at Tehran's 20th municipal district, due to its socioeconomic and cultural features has a notable variety and is definitely one of Tehran's districts of tourism and pilgrimage where a huge population of the city refer to everyday. It has many paths directed to the city main highways. Thus, considering its special features, this area can be a suitable sample for evaluating the city streets and safety parameters for emergency evacuation.

Literature review

Following studies related to our subject can be mentioned: Sherali and Carter (1991), housing site selection model and preparing algorithm for planning evacuation in the status of flood and storm [10]; Sattayhatewa and Ran (1999) presented a model for traffic dynamic management for evacuation of nuclear power stations. Considering the fact that all human are likely to be confused at time of emergency and loss their control and tranquility, they pointed that at this situation they compete for having a safety paths for exit. Thus, the roads may not be used effectively [11]; Cova and Johnson (2006) by examining emergency evacuation parts in and around the city, and the risk of following fire in the wake of earthquake, presented a model for dynamic simulation based on behavior [12]. In their study on location distribution for emergency evacuation and support coordination for crisis management, Yi and Ozdamar presented a model for direction, positioning, logistical coordination for resources, and evacuation operation for crisis stricken areas so as to improve level of services provision, quick access to stricken districts and temporarily positioning the ambulances centers in an appropriate location [13]. Yueming, XIAO Deyun (2008) provided a model and algorithm for emergency evacuation based on traffic in the city roads [14]. Sargolzaee and his colleagues (2002) examined the past earthquakes and found that the high level of death toll was owing to improper rescue operation [15]. Omidvar and his colleagues (2012) regarded intercity transportation network as the main factor affecting the crisis management in urban districts at the time of events and stated that applying for using the available paths will be at the most possible level at emergency situation due to the crisis [8].

Nowadays, with the development of different methods of constructing transportation routes, the routing problem is more complex than the past. Accordingly, the researchers are always seeking to find the best solution to the problem. But in the meantime, the city issue of emergency evacuation has been less dealt with. On the other hand, the standard indexes and parameters have not yet been defined for determining the need for the proper evacuation at emergency and relief stage. Due to the nature of earthquake-prone location of Iran on one hand, and existence of the metropolitans in Iran which have vulnerable structures and infrastructures against the earthquake, the call for addressing this issue is more and more required.

Methods:

This study is conducted on indexing, modeling and analysis of the relationship between the parameters of safety and determining the paths for emergency evacuation in 13th Aban neighborhood at Tehran’s 20th municipal district. To this end, the Analytical Hierarchy Process (AHP) has been used as the basic model. Therefore, based on undertaken literature study, analyzing the acquired data, and previous study’s results, a questionnaire has been prepared and submitted to the experts to be used for effective assessments of the parameters in transportation network. For evaluation and assessment of the judgments, Expert Choice software was used, and the techniques and capabilities for analysis available in the GIS, such as overlapping of the data layers has been employed as a supportive tool. The total flowchart of the process for determining the path appropriate for emergency routes has been shown in Figure 1.

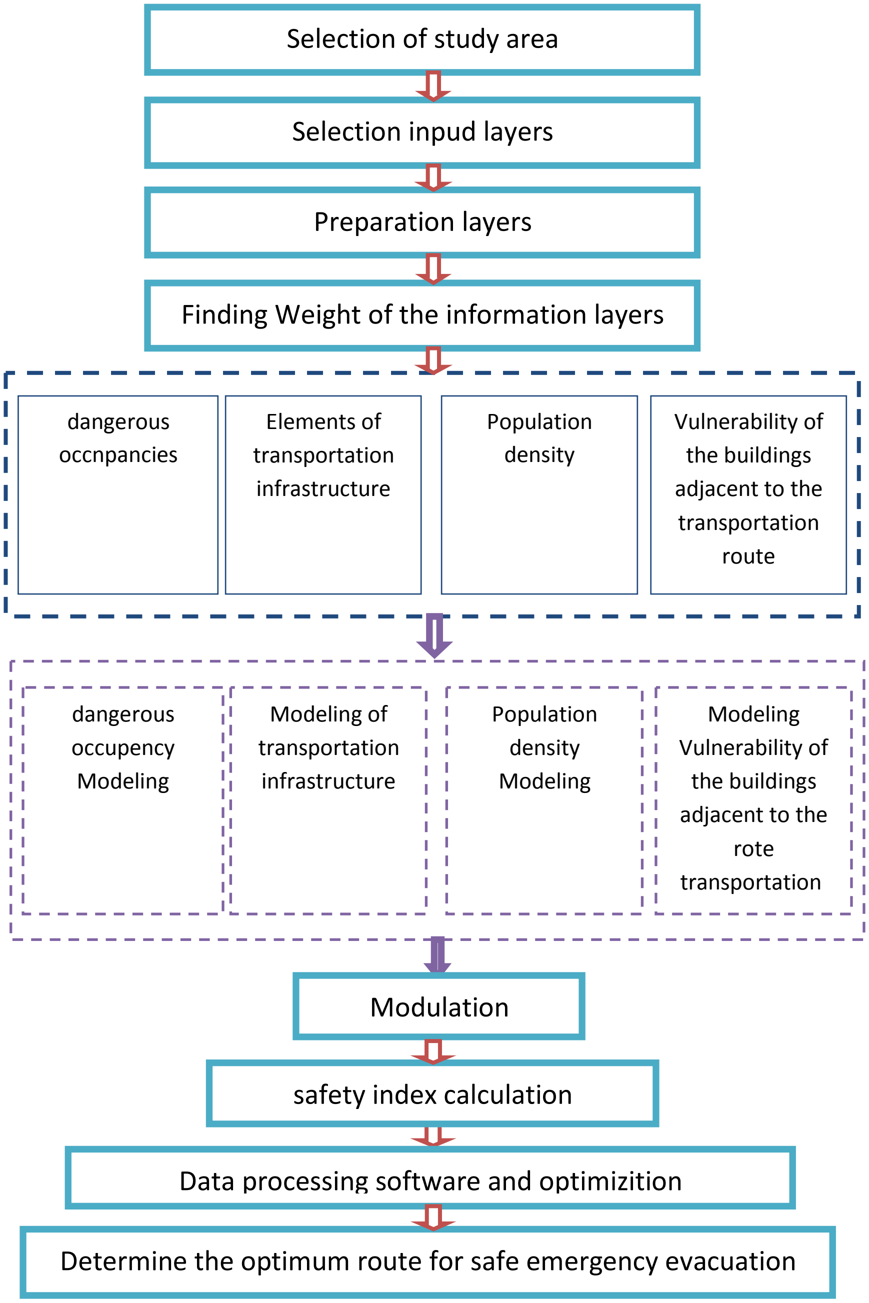

Figure 1 Total flowchart of the process for determining the optimal safe emergency routes

Defining the district of study:

The case of our study is located on a plain on the southern corners of Tochal mountains, which has been residential for many years. The Zone is the Ancient Rey, an old area in Tehran, which is now located at Tehran's 20th municipal district. It is 23 square kilometers within the Tehran's Municipality limit and 153 square kilometers outside it. Tehran's 20th municipal district is located at south of Tehran. From the north it is attached to districts 15, 16 and 19, from the south to the city of Qom, from the east to Pakdasht and Varamin and to Islamshahr and Zarandiyeh and Robatkarim from the west. Of major physical characteristics of the district 20 which can be referred to is its location at the south of Tehran, while it encompasses some of the main trans-regional administrative services of Tehran. The existence of such notable historical and religious places as the holy shrine of Imam Abdolazim (P. B. U. H.) has given attraction to the district. Its position for creating landscape of city is also prominent in a way that it is now considered as a main factor for ensuring the landscape integrity of Tehran. Having a population of over 91500 families, comprising of 5 internal districts and 2 external district and 21 districts has resulted in heavy load of daily trip to it. The 13th Aban neighborhood with 2750 square kilometers, nearly 24 percent of the district, and a total population of 31,945 people is limited from the of north to Azadegan Highway, from the south to 7Tir hospital, end of the street Sahraee, Amani, Molaii, Arabi, Enayati and Rajaie, from the east to Metro station wall with the length of 320 meters and to Behesht-e Zahra Highway from west with the length of 500 meters to Sahraee Street. Other data on 13th Aban neighborhood are given in Table 1.

Table 1 Description of the 13th Aban neighborhood [16]

Index	Unit	Amount
Population	Person	31945
Extent	Square kilometers	2750
Household	Households	19700
Green Space	Square meter	645848
Waste (monthly)	Thousand kilograms	1098
Open channels	Meter	1619
Covered channels	Meter	16000

Vulnerability of the 13th Aban neighborhood against earthquake: According to its place in Iran earthquake map, Tehran is exposed to risk of earthquake. In spite of this fact, according to studies by consultants of Iran and the Agency for International Cooperation of Japan (JICA) and the Center for Earthquake and Environmental Studies of Tehran, approximately 480,000 buildings in Tehran will received severe damages and about 220 billion dollars is estimated as the coast of damages in case of a strong earthquake. Damages incurred to the district 11, 12, 16 to 20 will be very high, about 80 percent. The 13th Aban neighborhood at Tehran's 20th municipal district has approximately 0.01 percent of worn buildings which is about 0.04 percent of the district and 0.02 percent of Tehran old structures. Thus, some parts of the 13th Aban neighborhood are more vulnerable in the event of earthquake. The extent of the damages likely to be inflicted on the population of the area in comparison with the whole district and city of Tehran, based on the plan for operational scenario is presented in Table 2, and a view of the streets to be studied in the network is shown in the Figure 2.

Table 2 the extent of the devastations and damages inflicted on the population of 13th Aban neighborhood compared to Tehran [16]

Status	In the neighborhood (No. of people)	With respect to whole district 20 (%)	With respect to the city of Tehran (%)
Number of deaths	217	10	0.6
The number of casualties requiring hospitalization	303	6	0.4
The number of casualties outpatient	2130	10	0.6
Number of DPs	22239	9	0.4

Figure 2 13th Aban street networks [17]

Based on the available studies, in case of an earthquake, the buildings in the north east of 13th Aban neighborhood will face high damages. The level of structural damages, based on the scenario, comparing to the whole district and Tehran, is shown in Table 3.

Table 3 structural damages in the area comparing to the whole district and Tehran [16]

Status	In the neighborhood (to the people)	With respect to the whole district (%)	With respect to the city of Tehran (%)
Heavy structural damage to the area	990	5.8	0.4
Moderate structural damage to the area	565	6.1	0.3
Partial Structural damage to the area	608	5.8	0.3

About 290 underground river channels (ghanat) in the northern area and 102 ones in the southern area of the district are distributed. In total there are 392 ghanats in the area which increase the level of vulnerability of the area to the earthquakes. All these specifications call for preparing comprehensive plans for identifying the paths and ways for emergency evacuation at the time of earthquake, since as earthquake occurs, in accordance with the increase in demand for using the road network, the efficiency of network will drop down. Therefore, lack of identification of the optimal emergency evacuation routs and unsafe or blocked paths certainly lead to the prolongation of rescue operation, evacuation of the devastated areas, heavy traffic load, inefficiency of rescue staff, and increase of damages and fatalities. But for identifying and determining the safe and optimal paths based on the safety index, we should find effective parameters on the safety of the routs with their degree of importance.

Using Analytic Hierarchy Process in assessment and determining the effective parameters on the safety of routs of rescue operation:

The technique of Analytic Hierarchy Process (AHP) is used in our study since it is simple, flexible, using both qualitative and quantitative criteria, and is able to analyze consistency in desirable and optimum judgments. [18].

AHP starts with identification and prioritizing of elements of decision-making. These elements comprise of four levels of objectives, indexes, parameters, and possible alternatives used in prioritization. The identification process of the elements and the relation between them results in a structure called the hierarchical structure. Conversion of the subject of study to a hierarchical structure is the most important part of AHP [19].

In the present study, for determining the effective safety parameters in selection of safe and optimum path for emergency evacuation, a questionnaire based on AHP is prepared and submitted to the rescue experts, crisis managers, urban planners, civil engineers, experts of earthquake and related fields. The experts have been asked to specify the parameters affecting the emergency evacuation based on their importance. According to yielded results from the experts’ suggestions, the influencing parameters on determining the safety of emergency evacuation paths are placed in group four. The final results are shown in the table 4.

Table No. 4. The process of AHP obtained from the experts comments in determining the effective parameters for determining the safety of emergency evacuation paths

objective (level one)	Parameters for determining the safety of emergency evacuation
indexes (level II)	Safety
Parameters (level III)	Vulnerability of the buildings adjacent to the evacuation route
	Population density
	Transportation structures like bridge
	dangerous applications
Options (Level IV)	1. Very dangerous 2.Dangerous 3.Moderate 4. Low Risk

Results:

Calculating weight (importance factor) of parameters

For determining the importance factor (wight) of the parameters, they should be compared pairwise. The basis of judgment of the comparison is a nine-quantity table presented in table 5. Based on this table and the study aim, the priority degree of parameter (i) is determined with respect to parameter (j). Therefore, for the index (n), (n^{n}) comparison of is made. Pairwise comparison is done in a matrix called “pairwise matrix of parameters”, the element of which are all positive and are introduced by the principle of "inverse condition" in AHP.

In order to determine the priority degree of parameters based on the experts and specialists opinions, 5888 comparisons were made and its results are presented in Table 6 and Figure 1. It is clear that the vulnerability of adjacent buildings of rout network is the major and most effective in determining the optimal and safe paths for emergency evacuation, thus the required actions for the safety and optimization of such buildings should have the outmost priority among related affairs.

Table No. 5. The nine-quantity table of pairwise comparison of indexes

Score (level of priority)	Definition	Description
1	Equal importance	Two criteria are of equal importance in achieving the goal
3	Slightly more important	Experience shows that to achieve the objective (i) is more important than (j)
5	More important	Experience shows that the importance of (i) is more than (j)
7	Much more important	Experience shows that the importance of (i) is much more than (j)
9	The absolute	The high importance of (i) is definitely proven over (j)
2, 4, 6, 8	Preferences interstitial	

Table 6 two-by-two comparison matrix of safety parameters index

Index	Vulnerability of the buildings adjacent to evacuation route	Population density	Transportation structures	dangerous uses	Normalized	Importance Factor (weight)
Vulnerability of the buildings adjacent to evacuation route	1	2.50	1.84	1.39	1.59	0.38
Population density		1	0.74	0.57	0.64	0.15
Transportation structures			1	0.76	0.86	0.20
dangerous uses				1	1.11	0.27

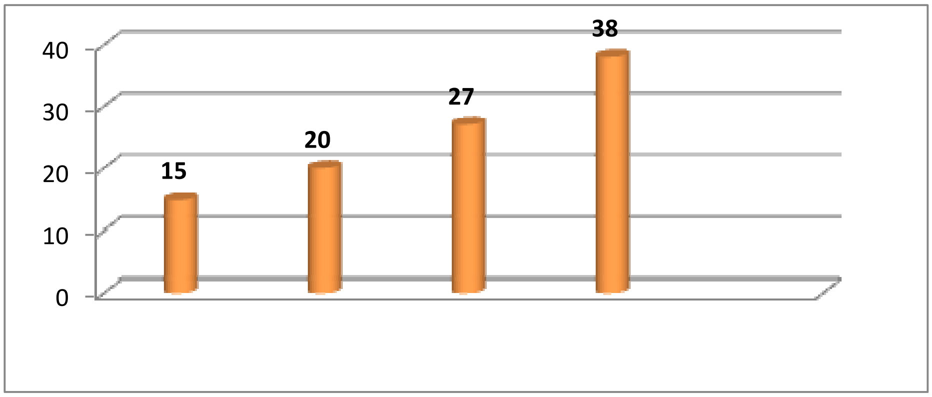

Figure 3 comparing the importance of parameters of safety index from experts' views

Consistency examination of judgments:

One of the advantages of AHP is the consistency examination of judgments for determining importance factor of the criteria and sub-criteria. When the importance of the criteria is estimated with respect to each other, there is possibility of inconsistency in the judgments. The mechanism for checking the inconsistency of judgments is determined by Inconsistency Ratio, which is calculated by dividing inconsistency index by random index. If the result is smaller or equal to 0.1, the consistency is acceptable; otherwise the judgments should be reconsidered. In other words, the matrix of two-by-two comparison should be established again.

Index of incompatibility $I.I. = \frac{(\lambda max - n)}{(n-1)}$

Certain number of random index (R.I.) can be extracted from Table 7.

Table 7: Table of random index computation

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

In the average geometric method which is an approximate one, instead of calculating the maximum possible value (λmax), L is used as following:

$$L = \left(\frac{1}{n}\right) \sum_{n=1}^{\infty} \left[\frac{AWi}{Wi}\right]$$

Where AWi is a vector of multiplication of the criteria of two-by-two comparison in the vector Wi (Weight vectors or importance factor). As mentioned above, the Expert Choice software is used for consistency Judgments determination. The index for judgment consistency; as CR = 0.00307 which is less than 0.1.

Modeling the parameters for safety index

The proposed model for assessment and implementation of safety index in this research includes examining the status of the adjacent buildings and roads and assessment of their vulnerability, the effect of hazardous applications in the area, checking the status of transportation structures, and population density. Modeling of each these parameters is shown in the figures 3, 4, 5 and 6.

In this level, the maps related to each indexes are analyzed by GIS software, the value of all maps are calculated in the matrix. Then, the calculated matrixes are put at the software written by research team which is based on the algorithm of the shortest path . After that, according to the supposed destination (which in our study is the intersection of Andisheh and Northern Sahara) the software will find the most optimal rout from all other intersections and paths.

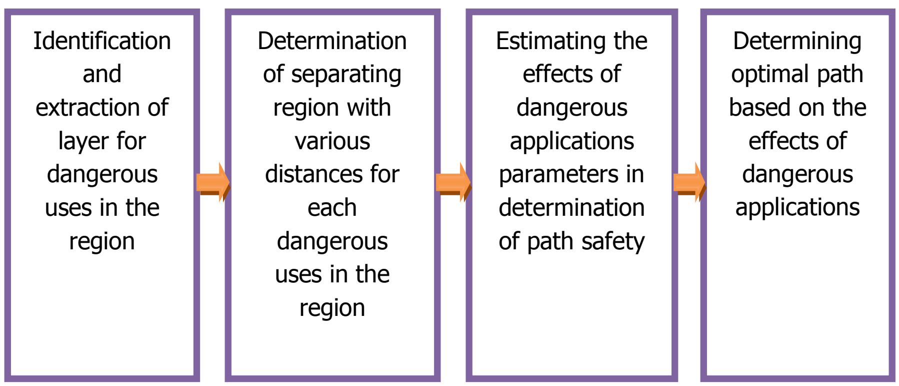

Fig 3 Method for estimation of the hazardous applications and its modeling

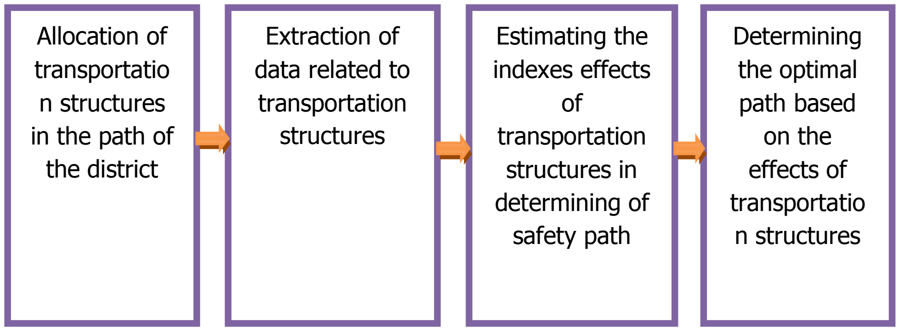

Figure 4 Method for estimation of transportation structures index and its modeling

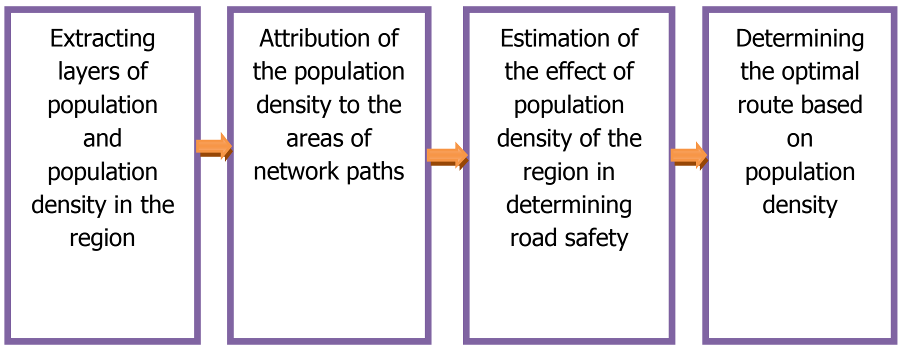

Figure 5 Method for estimation of population density and its modeling

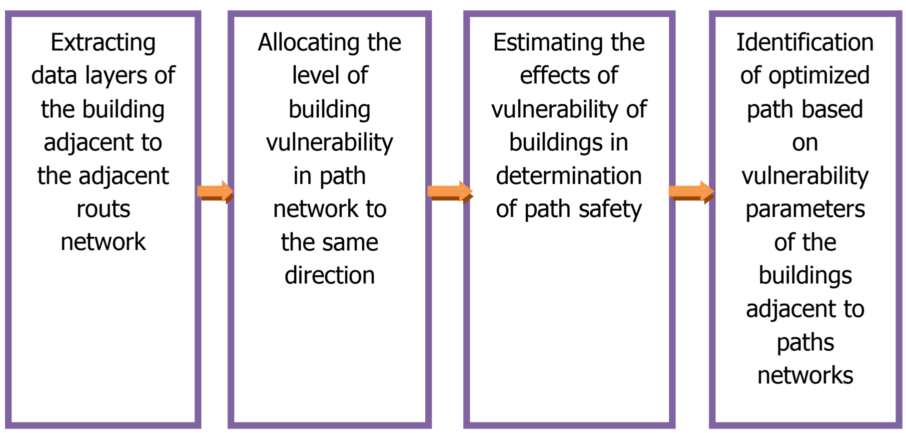

Figure 6 Methods for estimation of the vulnerability of buildings adjacent to the streets and its modeling

Discussion and conclusion:

By analyzing and assessing the effective parameters in safety of the paths for emergency evacuation in 13th Aban neighborhood by using AHP and considering the indexes of this study, many points can be mentioned, but the most important of them are:

1 - The optimal path for emergency evacuation for district 13th Aban neighborhood should be in form of figure 7. Places for emergency accommodation have been selected based on the available open spaces in the adjacent areas and the optimal safe paths from main intersections of district to places for emergency accommodation are specified.

Figure 7 the result of implementation of model of safety index on the district 13th Aban

2 - Many indexes are involved in selection of path, but the most important index in selecting the paths for emergency evacuation is safety. Safety include following indexes in priority order: 1. Vulnerability of the buildings adjacent to the road network and the heavy damages incurred on the buildings 2. Dangerous application 3. Transportation structures, 4. Population density in the residential complex blocks adjacent road network.

3 - With increase of the population residing at blocks adjacent to the road network, the optimal situation of paths used for the evacuation purposes drops down. In other words, the administrative paths which have more population are less suitable for optimizing process.

4 – Existence of bridges and tunnels on the emergency evacuation paths can be dangerous or even very dangerous. Therefore, no bridge should be constructed on the paths or at least the safety of buildings and its retrofitting should be properly observed.

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