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Determination of emergency roads to emergency accommodation using loss analysis results

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Abstract

This study presents a method to identify safe places to build temporary accommodation and accessible relief routes using the results of damage analysis for an earthquake within the bounds of probability for the city of Shiraz in Iran. The commonly used HAZUS damage estimation method was used. The most influential factors on the location of safe temporary accommodation in Shiraz were determined by use of the damage results, the Analytic Hierarchy Process (AHP) model, and Expert Choice software. A map for the resulting optimal locations of temporary accommodation was prepared. Subsequently, all of the parameters influencing the safety of emergency evacuation efforts and the relief network were identified and the impact rate of each one was determined based on expert opinions through AHP. Based on the resultant importance of each index, roads were weighted and coded. The optimally safe routes for relief and emergency evacuation were determined. The results suggested that different indices suggest different relief routes and the optimal route was obtained through overlapping the data layers according to the importance of each parameter. This optimal route could provide maximum services in the minimum time and subsequently create capacity building in urban crisis management.

Keywords: Earthquake, Emergency accommodation, Damage, Emergency evacuation, AHP

Introduction

Building type and structure of the city is considered as one of the influential factors in decreasing vulnerability among the cities, especially damages due to earthquake. Thus, it is possible to decrease the vulnerability through planning, fundamental urban design, and capacity building in crisis management (Norouzi Khatiri et al. 2013). A decrease in vulnerability against earthquake among urban communities occurred when the safety was considered in all planning levels, among which determining and optimizing relief and emergency evacuation roads is considered as one of the issues which can play a significant role in decreasing the casualties and damage rate if implemented (Ganjehi et al. 2013, 2014, 2017).

Emergency evacuation is a complex process involving the rapid and safe evacuation of people to a safe area as far away from danger as possible (Southworth 1991). The relevant methods and models mainly consist of evacuation demand generation, destination selection (me.e. shelter), and route selection. The evacuated spatial distribution under different scenarios is the basis for modeling the evacuation demand generation in disaster areas. Some studies used reliable demographic data in this area (Jones et al. 1983; Glickman 1986; Kitamura 1988; Chin and Southworth 1990).

Considering the selection of the best evacuation route, most studies use a distance-based function such as the Euclidean distance or the grid route distance, as the main parameter to calculate travel costs, but others consider the main function as the main time. Based on these constraints, the best evacuation route can be selected and a set of evacuation simulation models can be

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generated (FEMA 1984; Sinuany-Stern and Stern, 1993; Pal et al. 2003; Hamza-Lup et al. 2004; Zou et al. 2006; Uno and Kashiyama 2008; Jotshi et al. 2009).

Hence, considering capacity building in urban crisis management, determining and optimizing relief and emergency evacuation roads after disasters, as well as finding the safest emergency accommodation are really important.

Some suggested that post-disaster measures such as temporary accommodation programs should be performed in advance and included in urban and regional planning (Wei et al., 2012; Killings, 2011; Crawford et al., 2010; Johnson, 2007; Bologna, 2007; Alexander, 2004).

HAZUS was introduced by Federal Emergency Management Agency (FEMA) in order to predict damage after earthquake which estimated damages in a city or an area (FEMA, 2003). Based on HAZUS method, the number of people who need temporary accommodation depend on income, ethnicity, ownership, and age. However, the method might underestimate the temporary accommodation for needy people (Tamima and Chouinard, 2016). In addition, some changes may occur in the number of the people who evacuated and moved to the temporary accommodation in different stages. According to Central Disaster Prevention Council (CDPC) report, the number of victims evacuated to shelters after the earthquake in Niigata, Japan in 2004 reached to its highest point, reached to more than 100,000 4 days later, and finally decreased to 10,000 persons until the end of the first month after the earthquake (Li et al. 2017).

Sherali et al. (1991) studied locating shelter model and providing an algorithm to plan the evacuation in some situations such as flood and typhoons. Dunn and Newton (1992) found a set of roads to minimize the total distance in a network with capacity limitations by formulating the evacuation routing in the form of minimum flow cost for two algorithms. In this regard, Sattayhatewa and Ran (1999) proposed a model of dynamic traffic management for nuclear power plants evacuation and explained that humans are generally panic during the crisis and lose their control and calmness. In such situations, individuals compete for finding the exits without considering the others. As a result, the road network might not be efficiently used. In this study, Chen and Zhan (2014) analyzed a simulating method for different evacuation strategies under different road network structures. By studying the emergency evacuation in urban areas close to flammable locations and facilities, Cova and Johnson (2002) provided a method of dynamic simulation based on behavior. Poorzahedy and Abulghasemi (2005) believes that travel time (displacement) plays the most important role among different

factors involved in designing transportation networks in emergency situations after earthquake. Further, Yi and Özdamar (2007) explained a location distribution model for emergency evacuation and support coordination for crisis operations. The routing and locating model conducted some resources for logistic coordination and evacuation operation in crisis-stricken areas in order to maximize the level of responsiveness and quick access to the effected areas for locating temporary emergency centers in suitable locations.

Tzeng et al. (2007) provided a definitive multi-criteria model for the emergency distribution of goods to the damaged areas by considering expense, response time, and customers' satisfaction. They solved this problem by fuzzy multi-objective programming. Liu et al. (2011) studied the 7.1 Richter magnitude destructive earthquake in Yushu area in China in 2010 by which 2698 people died. They explained the effective parameters in intensifying damages in addition to rebuilding experiences, as well as bringing the area back to the pre-earthquake situation by considering the role of private and governmental organizations in victims' relief, especially providing accommodations. Based on the result, special environmental situation of the area and lacking infra-structures equipment for relief had the most effective role in the severity of casualties.

Yueming and Deyun (2008) proposed a model and algorithm for emergency evacuation only based on traffic in city roads. Omidvar et al. (2012) reported that the city road network is the most important factor in crisis management in urban areas during disasters and emphasized that the demand for using the available road network reached to its maximum during the disasters.

Rein and Corotis (2013) evaluated possible consequences of large earthquakes in Denver, U.S. They focused on active seismographs in this area and possible damages of earthquake after peoples' well-preparation for increasing their understanding. Bayram et al. (2015) studied the problems of locating earthquake shelters and evacuated people in Istanbul earthquake to minimize evacuation time. The focus of most evacuation surveys was on effective parameters on casualties (Dombroski et al. 2006; Jonkman et al. 2009; Zahran et al. 2013; Yu and Wen 2016) or relationship between evacuation time and crowd congestion. Wood and Schmidtlein (2013) and Fraser et al. (2014) used least-cost distance analysis in their survey for evaluating the required time duration in tsunami evacuation.

Xu et al. (2018) provided a hybrid bilevel model for emergency accommodation in earthquake and considered the number of the evacuated people in a dynamic form. In addition, they compared the implemented model to the results of multiple objective models. Some solved this model by locating complexes through

presenting discovery optimizing algorithms and this problem was not solved by traditional mathematical solutions.

Unfortunately, emergency evacuation, as well as improving emergency evacuation road and relief after earthquake, has been neglected in Iran due to the unpredictable nature of earthquake. The present study aimed to determine the most optimal emergency evacuation road to the safest emergency accommodation through using the concept of integrating damage analysis, indexing the emergency evacuation and Analytic Hierarchy Process (AHP) algorithm optimally. In other words, the main research question is the damage risk analysis of buildings against possible

earthquake and damage estimation by considering the probability of this hazard and determining the emergency accommodation and its accessible roads. The maximum relief could be provided in minimum time during the earthquake by determining and optimizing relief roads. Hence, it was possible to move the victims to the safest accommodation in the minimum time by determining the most optimal relief road, which was provided by coding.

Methodology

Iran is located in the middle east and Shiraz is located in the south of Iran. Shiraz is the third Metropolis of Iran and the capital of Fars Province. Figure 1 shows the

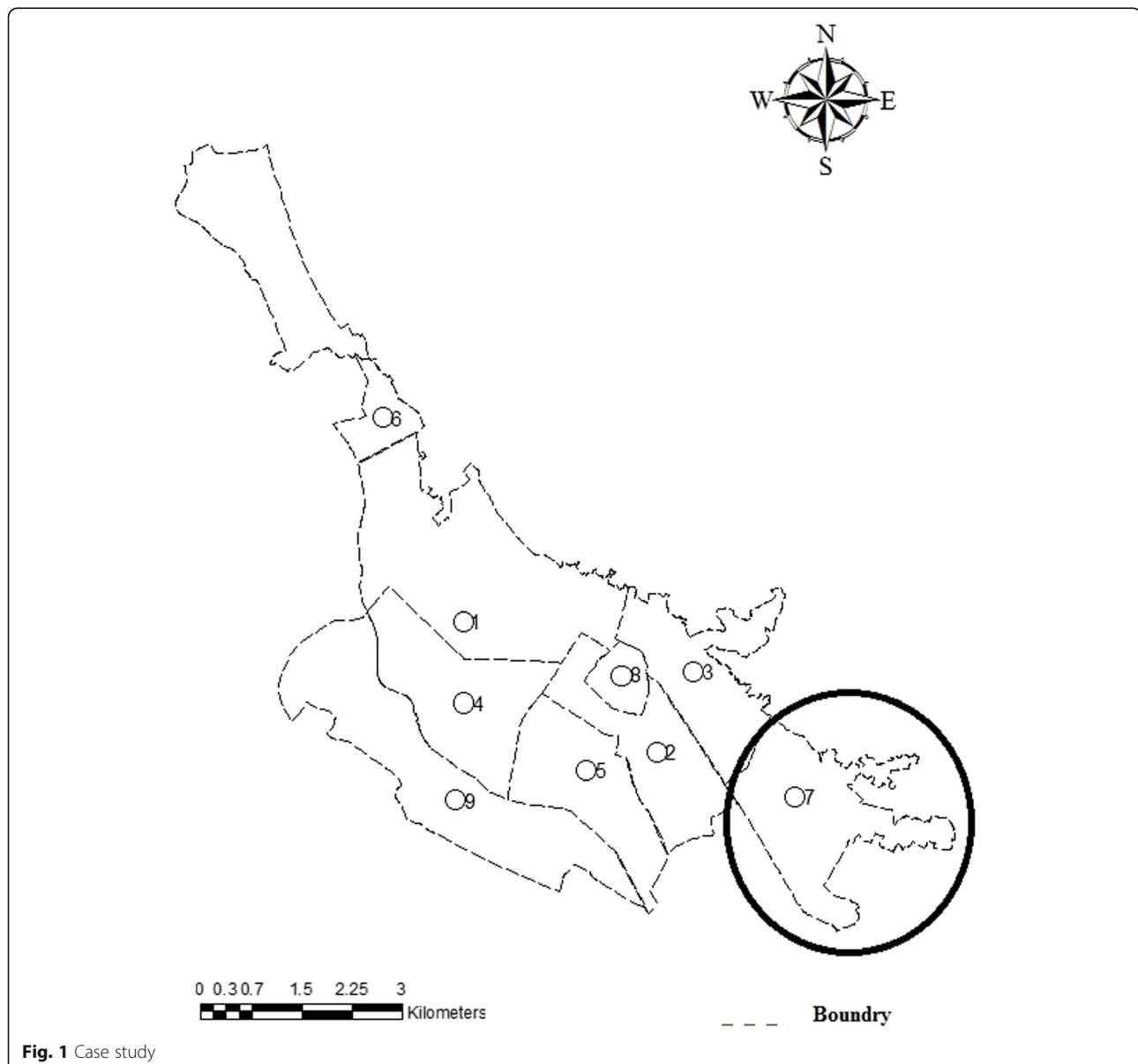


Fig. 1 Case study

urban areas of Shiraz and the faults of this city. The study area (district 7) in this city is marked with a circle on the map.

In general, this study is divided into three modules as follows.

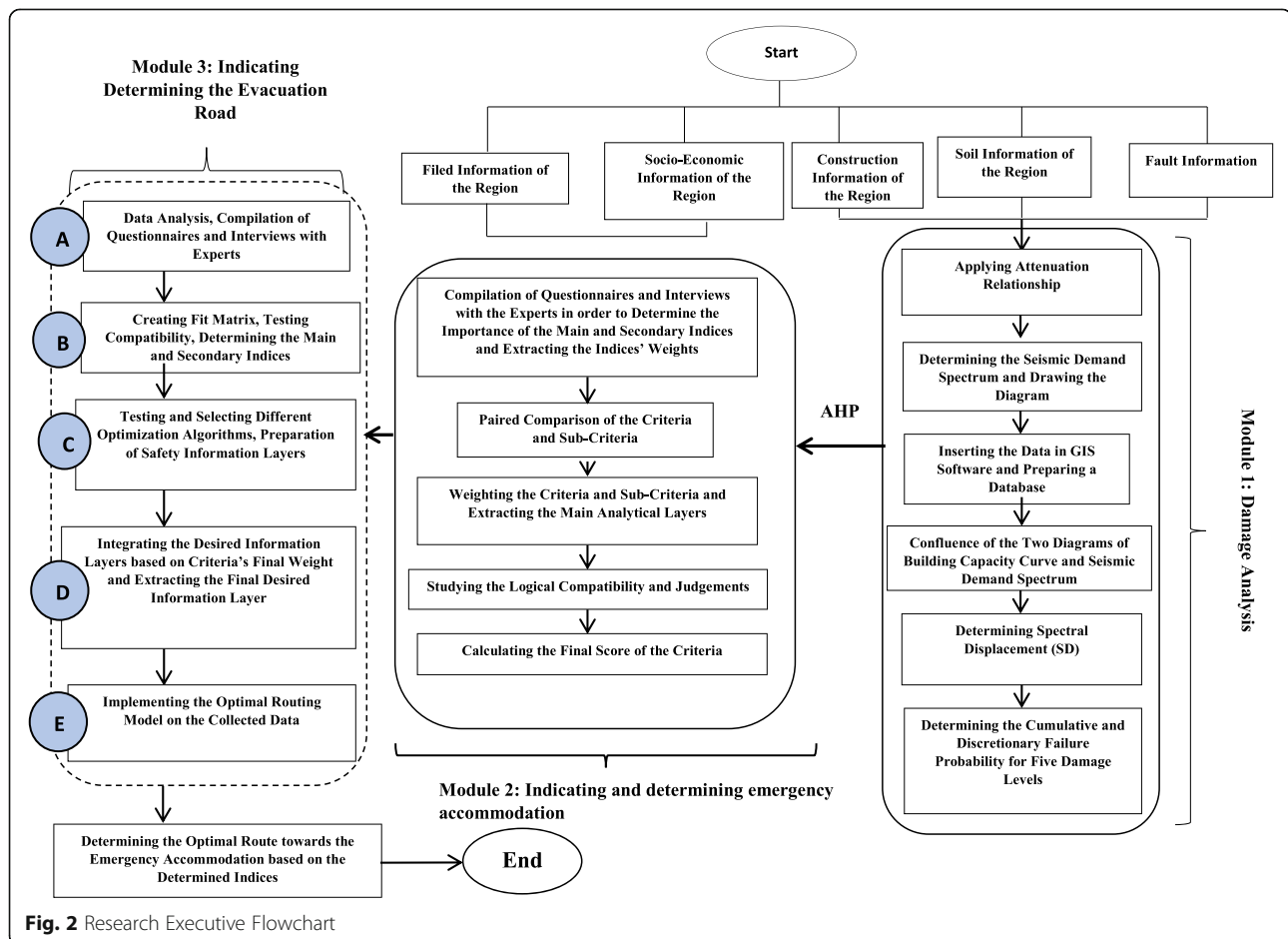
- Analyzing earthquake damage of buildings in the study area
- Indicating emergency accommodation and selecting the best accommodation area
- Representing evacuation routes and determining the best route from the nodes to the emergency accommodation (steps A to E)

As shown in Fig. 2, the instruments used in this study included statistical methods for probability determination of earthquake damage in different damage levels, GIS, and coding for optimizing the emergency roads and AHP algorithm.

The Analytic Hierarchy Process (AHP) enables decision makers to determine the interaction and simultaneous effects of various complex and uncertain

situations Momeni (2007). Multi-criteria decision-making methods include all structured methods helping experts to make decisions based on more than one criterion (Kuo et al., 2006). In other words, multi-criteria analysis usually provides the conditions for decision makers to make qualitative evaluations to determine the performance of each option according to each criterion and the relative importance of the criteria based on the objective (Deng, 1999). Hierarchical analysis process method, as one of the multi-criteria decision making methods (Yu, 2002), allows decision makers to quantify non-objective factors (Taleai et al. 2009).

GIS was used in hazard analysis, and the data were inserted in its layers by linking tables of the damage analysis due to the disasters for the building blocks. Further, AHP method was used for locating the emergency accommodation. The AHP method standard tables were distributed among the experts. These experts were selected based on some factors such as having enough knowledge of decision-making parameters and professional background for a long time. After integrating the paired comparison tables, the data were inserted



in Excel and MATLAB and the ultimate weight related to each table was calculated by using geometric mean and calculating the final paired comparison tables. Ultimately, the emergency accommodation locations were determined by using the studied region maps. In order to determine the most optimal access to the emergency accommodation, the following research method was implemented and the flowchart below shows its stages.

Stage A: In this stage, after studying the documents available in the libraries, analyzing the retrieved data, and considering the results derived from the review of literature, a questionnaire was developed based on AHP model and distributed among the 23 experts in order to extract the effective parameters in determining the optimal roads.

Stage B: Based on the experts' opinions, the required initial data were collected and Expert Choice software was used to assess the judgments adaptability. According on the experts' opinions, four main sub-criteria were derived among the 10 proposed sub-criteria. These sub-criteria were much more effective than other sub-criteria. Then, the final score and their effective rates were calculated through the manual method and Expert Choice software.

Stage C: The shortest road problem and its algorithm were studied from the safety point of view. Initially, the algorithms of All to All and Dijkstra's shortest path were implemented to find the shortest road between the source and the destination nodes. This implementation was carried out in VC++ and Visual Basic software. therefore, some programs were coded in the software. The input of these programs was a graph similar to the roads network and the output were nodes which determined the shortest path between the first and last nodes based on weight. In the first software, different sources and destinations were entered. Then, the data were analyzed and the optimal path was presented between the two points, while only the destination was entered and the optimal path from any conjunction in the studied region was shown in the second software.

Stage D: In this stage, the data layers for each sub-criterion were produced to determine the score of each path using capacities and analysis techniques of GIS software, and the data for each main path was extracted in the studied region.

Stage E: Two types of software were used to study the derived optimal path and evaluate the results. In this stage, the results derived from the studies and the scores of each main road in the studied region were inserted in the software as the input in order to derive the optimal emergency roads.

Risk analysis module

Attenuation relationship

Some studies explained the procedure to select appropriate attenuation model for seismic hazard analysis (Stewart et al. 2015; Shoushtari et al. 2016; Mase 2018; Tanapalungkorn et al., 2020; Zare et al., 1999; Mase et al. 2020; Mase 2020).

Choosing an appropriate reducing relationship to be used in seismic hazard analysis is very important since the result of seismic hazard analysis is significantly affected by. Definitely, the best attenuation relation for use in a particular area is the one which is prepared by using the information available in that area. It is worth noting that geological, tectonic, fault rupture mechanisms, and focal depths of earthquakes in an area affect how strong ground motion changes with distance in that area, while the mentioned parameters are not considered in many attenuation relations. therefore, a relationship established by using the information from the same region should be used to address some of the mentioned shortcomings. Although the use of area-specific attenuation relations is an ideal option, such selection power does not always exist since the lack of recorded information in many areas eliminates the possibility of extracting a suitable statistical relationship for those areas. In such cases, the only logical and possible option is to use the relationships which were determined in the areas similar to the one in question. The similarity between the two regions means that the seismic and tectonic conditions of the two regions are more or less the same.

Based on the mentioned issues, attempts were made to use appropriate attenuation relations consistent with the tectonic conditions of Iran. Thus, Zare' attenuation relationship (1999) was used in this study.

Based on the conducted studies on Iranian Strong Motion Data collected from all over Iran, Zare et al. (1999) could provide attenuation relationships for Iran by choosing and modifying 498 three-component maps. The attenuation model of calculating peak ground accelerator (Zare et al., 1999) is as follows.

$$\log A = a.M + b.X - \log X + C_i S_i + \sigma.p \quad (1)$$

where A is the considered parameter (peak ground accelerator), M shows the Moment magnitude, X indicates the focal distance (km), C is considered as the site coefficient (S), and σ means the standard deviation. The standard deviation was added to the mean value ($P=0$) by assuming $P=1$. In this equation, C_1 is the stone site, C_2 shows the hard alluvium site, C_3 indicates soft alluvium (sand) site, and C_4 is the soft (clay) site. Table 1 indicates the coefficients used in Zare et al.'s (1999) attenuation relationship.

Table 1 Attenuation relationship components (Zare et al., 1999)

Region	A	B	C ₁	C ₂	C ₃	C ₄	Σ
Central Iran – Alborz (Vertical Component)	0.322	−0.0003	−0.828	−0.754	−0.971	−0.788	0.352
Central Iran – Alborz (Horizontal Component)	0.322	−0.0004	−0.688	−0.458	−0.72	−0.585	0.394
Zagros (Vertical Component)	0.406	−0.0038	−1.262	−1.333	−1.23	−1.777	0.356
Zagros (Horizontal Component)	0.339	−0.0019	−1.047	−1.065	−1.02	−0.975	0.329
Iran (Vertical Component)	0.362	−0.0002	−1.124	−1.15	−1.139	−1.064	0.336
Iran (Horizontal Component)	0.36	−0.0003	−0.916	−0.852	−0.9	−0.859	0.333

Considering the conducted studies, the site of the studied region is in hard alluvium category. Hence, $S_2 = 1$, and S_1 , S_3 , and S_4 are equal to zero

Standard response spectrum preparation

Regarding HAZUS instruction, ground reflection spectrum (S_{AS} Short-Period Spectral Acceleration of Soil Type i) and S_{ALi} 1-s period spectral acceleration of Soil Type i) is determined based on the region shear wave velocity and soil type, which is modified by Eq. (2).

$$S_{ASi} = S_{AS} F_{Ai}, S_{ALi} = S_{AL} F_{Vi}, T_{AVi} = \left(\frac{S_{ASi}}{S_{AS}} \right) \left(\frac{F_{Vi}}{F_{Ai}} \right) \quad (2)$$

The standard response spectrum including the following variables is calculated as follows.

- Constant spectral acceleration (The constant numerical acceleration is equal to S_{AS} in the time interval less than T_{AV})
- Constant spectral velocity (The acceleration corresponds to $1/T$ in the time interval $T_{AV} < T < T_{VD}$)
- Constant displacement (The acceleration corresponded to $1/T^2$ in the time interval $T > T_{VD}$)

Earthquake damage analysis module

Based on the above-mentioned details, seismic demand spectrum and structure capacity diagrams were calculated. Considering the SDs calculated from the intersection of the above-mentioned diagrams, median, and β of each structure, the cumulative probability was measured for five levels of damage in the buildings based on Eq. (3). Then, the discrete probability for different levels of damage is calculated as shown in Eq. (4).

$$P(d_s | S_d) = \phi \left(\frac{1}{\beta_{ds}} \ln \left(\frac{S_d}{S_{d,ds}} \right) \right) \quad (3)$$

where $S_{d,ds}$ is the median of spectrum displacement in damage state ds , β_{ds} means the standard deviation of natural logarithm in spectral displacement for the damage state ds , and ϕ is considered as the normalized cumulative distribution function.

In general, the calculated values of cumulative probability (PCOMB) of failure at a risk level and exceeding that risk level are as follows.

$$1 \geq P_{COMB}[DS \geq S] \geq P_{COMB}[DS \geq M] \geq P_{COMB}[DS \geq E] \geq P_{COMB}[DS \geq C] \quad (4)$$

where DS shows damage state, and S, M, E, and C indicate slight, moderate, extensive, and complete damage, respectively. COMB indicates the combined probability for the damage state due to occurrence of ground failure or ground shaking. The discrete probabilities in a given damage state are shown as Eq. (5).

$$\begin{aligned} P_{COMB}[DS = C] &= P_{COMB}[DS \geq C] \\ P_{COMB}[DS = E] &= P_{COMB}[DS \geq E] - P_{COMB}[DS \geq C] \\ P_{COMB}[DS = M] &= P_{COMB}[DS \geq M] - P_{COMB}[DS \geq E] \\ P_{COMB}[DS = S] &= P_{COMB}[DS \geq S] - P_{COMB}[DS \geq M] \\ P_{COMB}[DS = \text{None}] &= 1 - P_{COMB}[DS \geq S] \end{aligned} \quad (5)$$

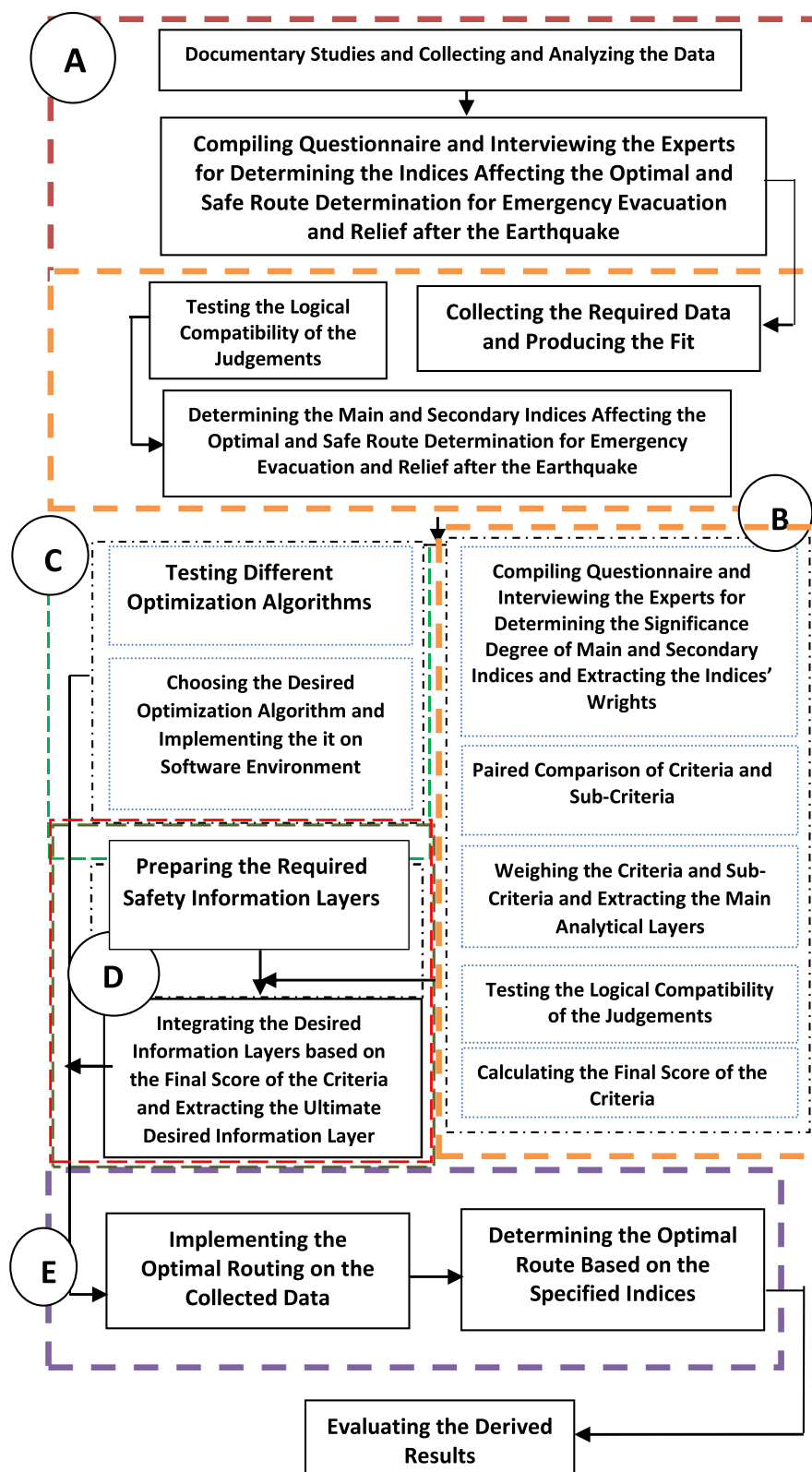
Different levels of damage probability should be considered for different types of structures. For each case of damage, the probability of damage to any type of structure is weighed against all buildings regarding the fraction of the total area of the building as shown Eq. (6).

$$POSTER_{ds,i} = \sum_{j=1}^{36} \left[PMBTSTR_{ds,j} \times \frac{FA_{i,j}}{FA_i} \right] \quad (6)$$

where $PMBTSTR_{ds,j}$ means the probability of the model building type j being in damage state ds , $POSTER_{ds,i}$ shows the probability of occupancy class i being in damage state ds , $FA_{i,j}$ is considered as the floor area of model building type j in occupancy class i , and FA_i represents the total floor area of the occupancy class i .

Locating emergency accommodation

In this section, the data related to locating concepts and models and locating index and criteria were collected by considering the available literature review

**Fig. 3** General Stages of Emergency Evacuation

along with the available domestic and international documents by referring to the experts related to the research field through questionnaire and interview. In the practical part of this study, some parts of the data were collected from maps and GIS layers of Shiraz and other parts were collected through interviewing the Crisis Management Organization and municipal experts. ArcGIS software was used to analyze the collected layers. Among the locating models, two-dimensional logic model was selected as a model in which the locating was conducted. Then, AHP model was used for prioritizing and selecting the most proper location among the derived locations. Finally, expert Choice software was used for hierarchical process analysis.

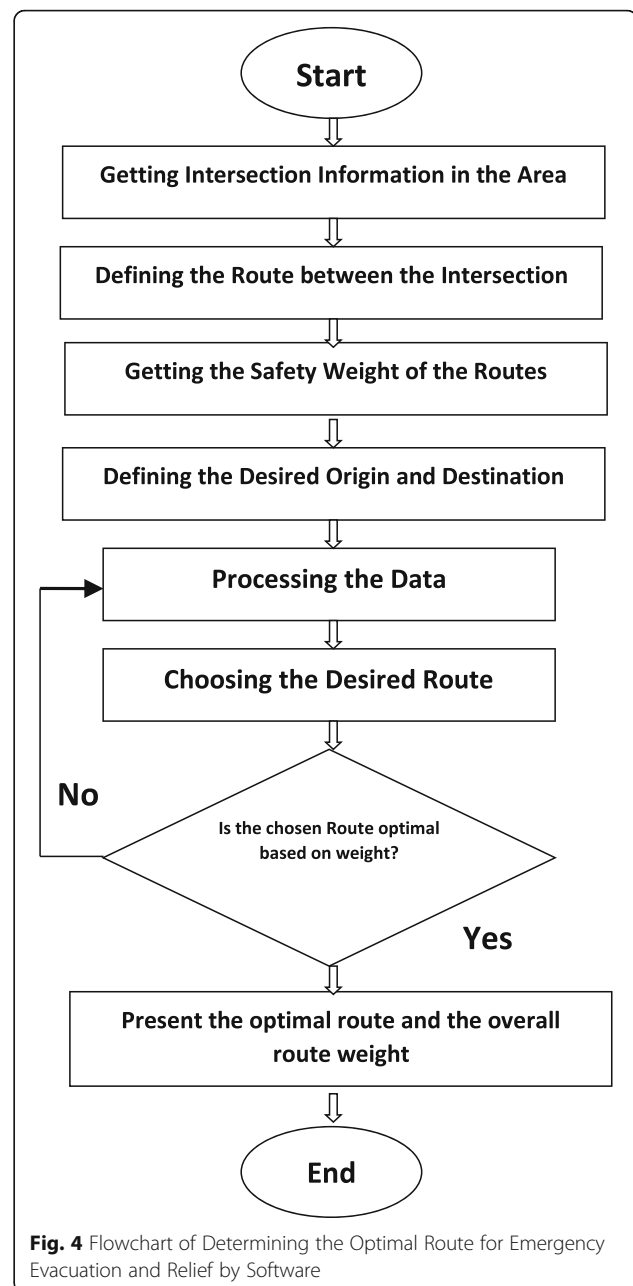
In the present study, the criteria were weighted by using hierarchical process analysis (Expert Choice software), and then integration and phasic logic were used. Locating process was conducted based on modeling the current and predicated situation, which was implemented by MacCoy and Johnston's conceptual modeling. Based on this method, these centers were located by using spatial analyzer through proper location maps which showed the most and least proper places for locating a certain activity based on a special subject such as fault). The data in these studies were analyzed based on the layers presented in the locating model. The elements were analyzed to create the map in two steps. First, the convenient location maps were prepared for some elements and the initial map of the convenient locations was prepared for creating the accommodation centers after their combination with other elements. During the second stage, the convenient situations for the accommodation centers were determined in the studied area by inserting other maps such as the limits.

Emergency evacuation

Optimal road determination stages

In order to determine the optimal route, the A to E steps, which are given in the form of a research, should be performed in the form of two flowcharts as shown in Figs. 3 and 4:

Figure 3 shows the general steps of an emergency evacuation operation. Based on this flowchart, a questionnaire was developed and provided to experts to extract the effective parameters based on hierarchical analysis model in determining the optimal routes and assess the compatibility of experts' judgments with EXPERT CHOICE. Based on the determined indicators and score (weight) in each of these indicators, different data layers were weighted,



and accordingly the best available route was determined from different nodes in the study area to the emergency evacuation site.

Figure 4 displays the operations performed in Section E in Fig. 3. In this step, information about the routes and weight of their data layers were entered into the software and the desired origin and destination were defined. The data were processed by the software and the cycle of selecting routes between the points of origin and destination continued until

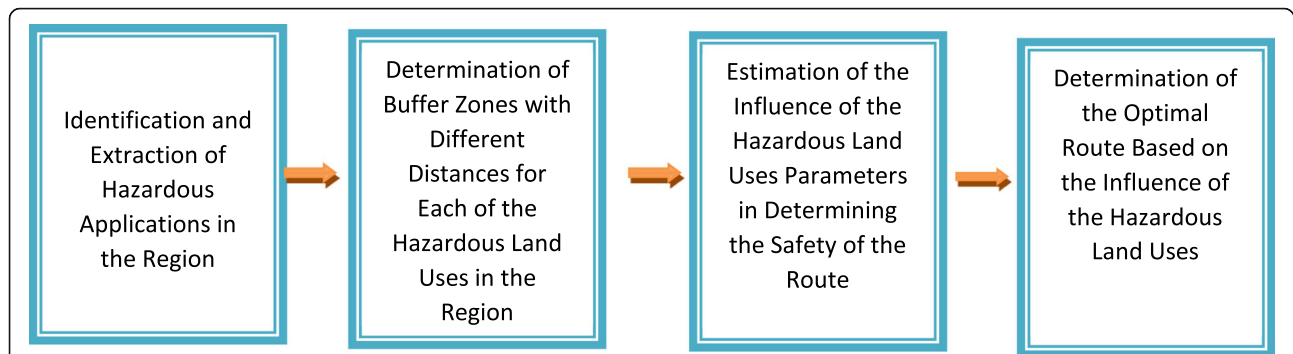


Fig. 5 Estimating hazardous land use index method and its optimal road determination

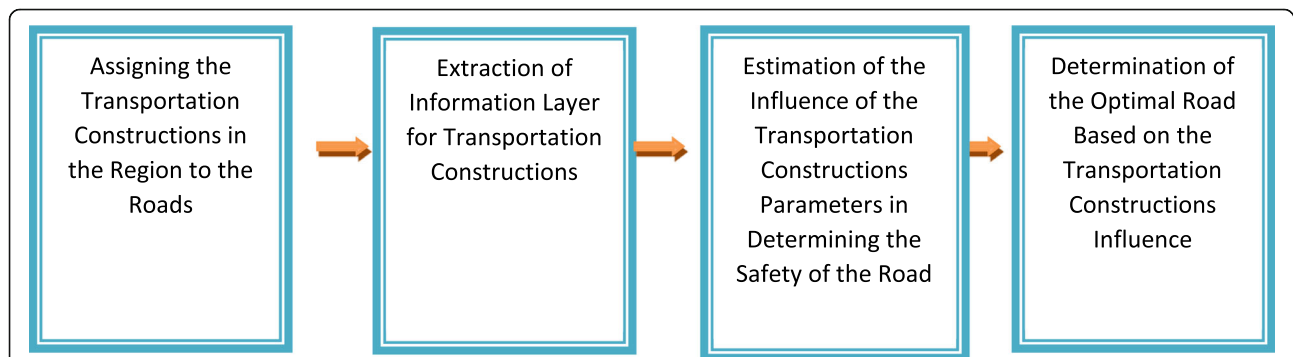


Fig. 6 Estimating transportation constructions index method and its optimal road determination

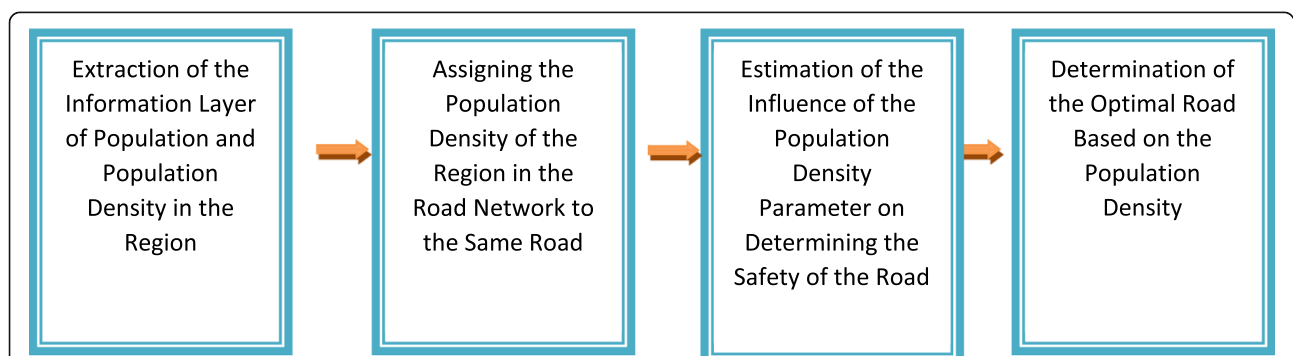


Fig. 7 Estimating population density index method and its optimal road determination

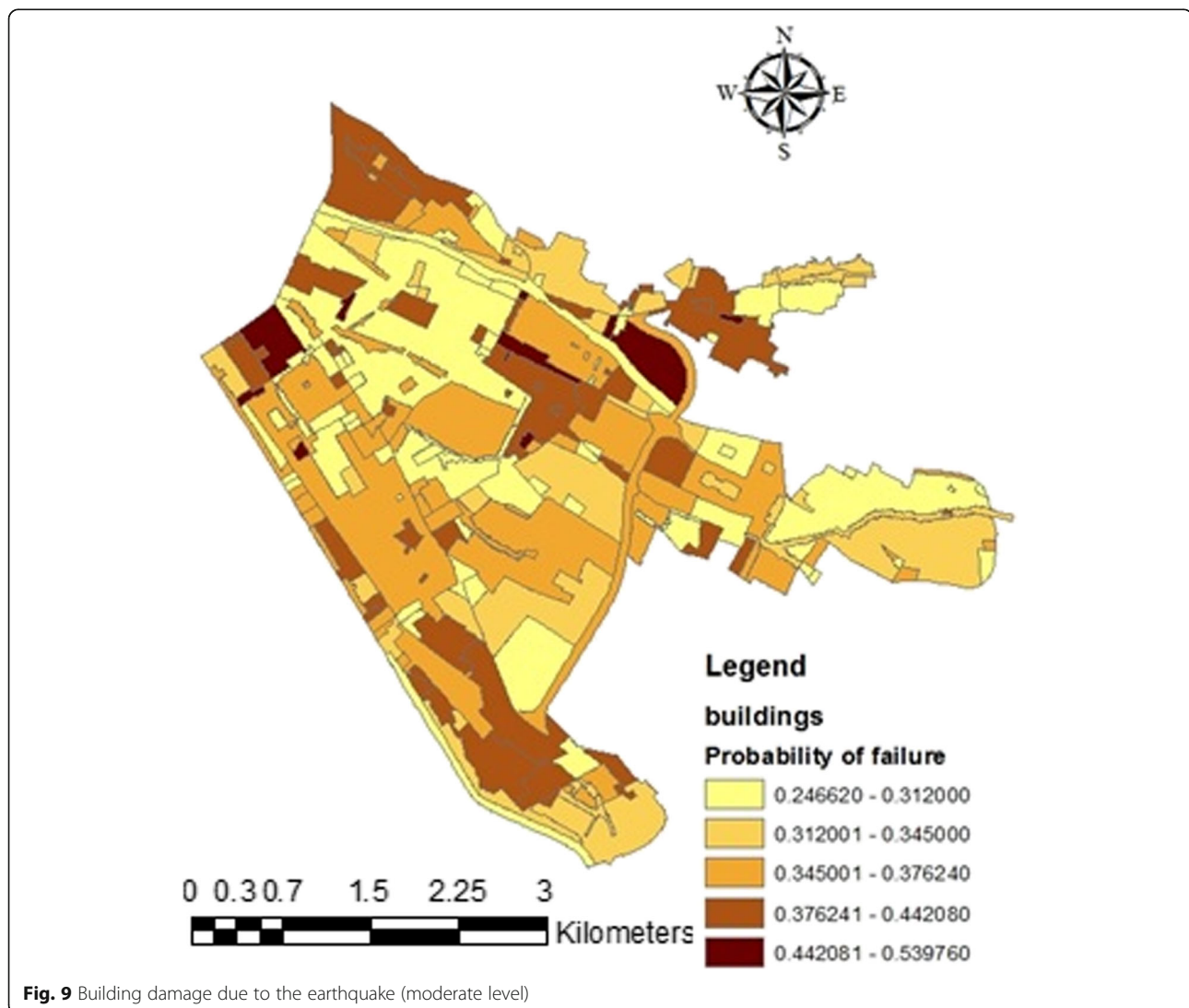
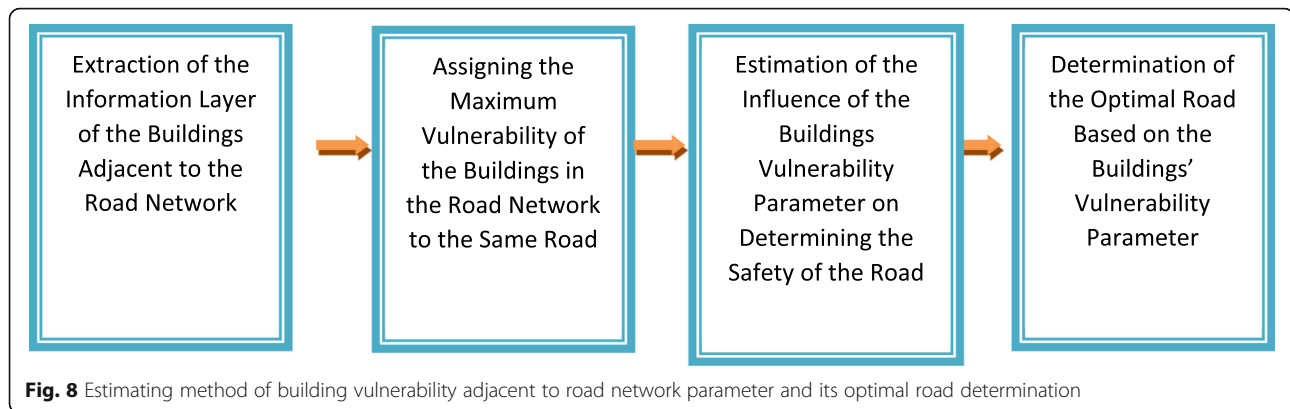
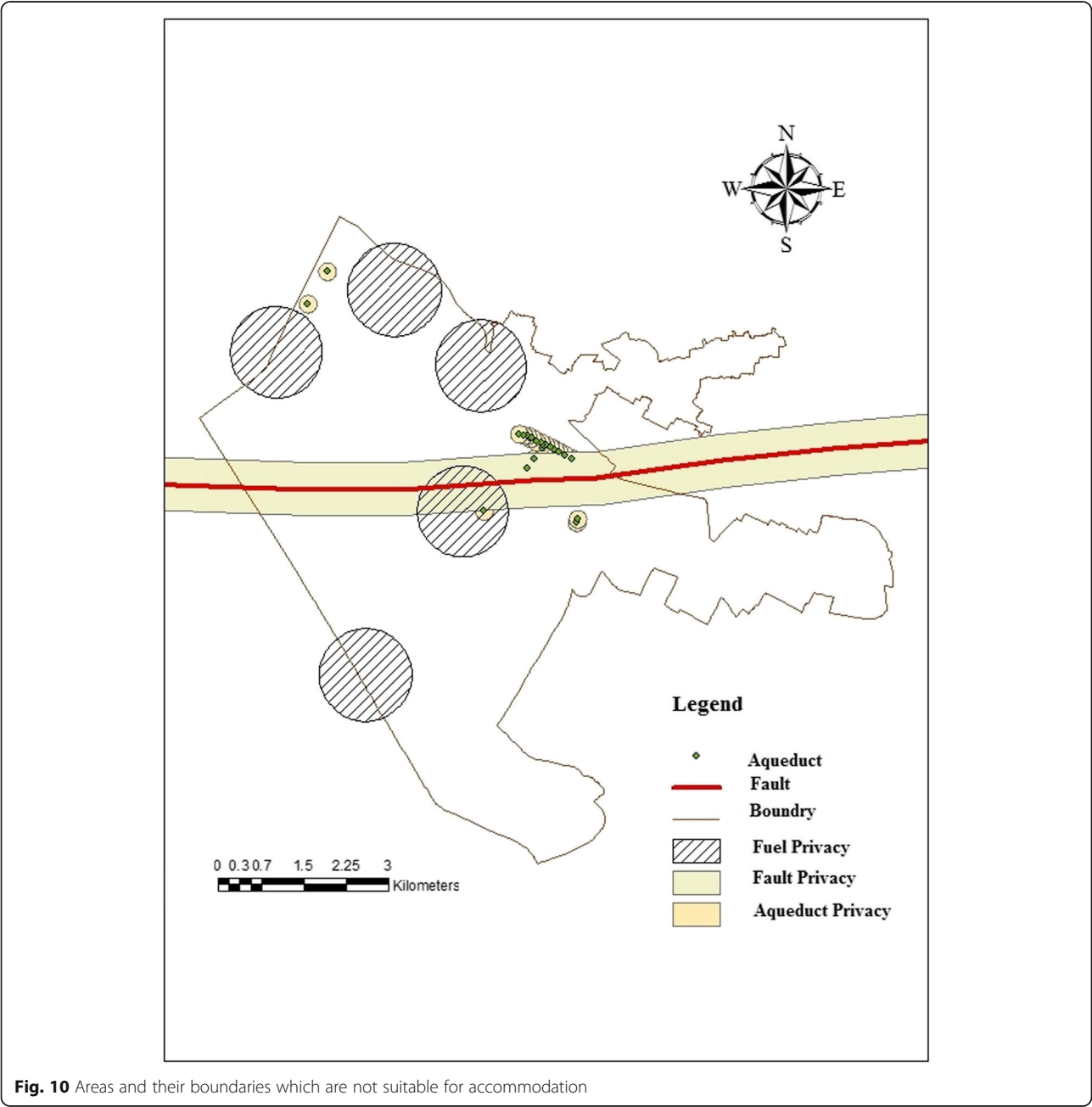


Table 2 Studying the compatibility of the judgments in determining the coefficients of major indices using MATLAB

Incompatibility rate		
CRm	CRq	Compatible status
0.035	0.087	



selecting the best possible route for emergency evacuation.

Modeling safety index parameters

The model proposed based on the experts' opinion included examining building construction adjacent to the road networks and evaluating their vulnerability, evaluating the effects of Hazardous land use in the region, and investigating the transportation constructions and population density in the studied region in order to assess and implement safety parameter of city roads.

Figures 5, 6, 7 and 8 show the general steps related to the extraction of data layers, estimating the impact of each parameter in determining the safety of routes, as

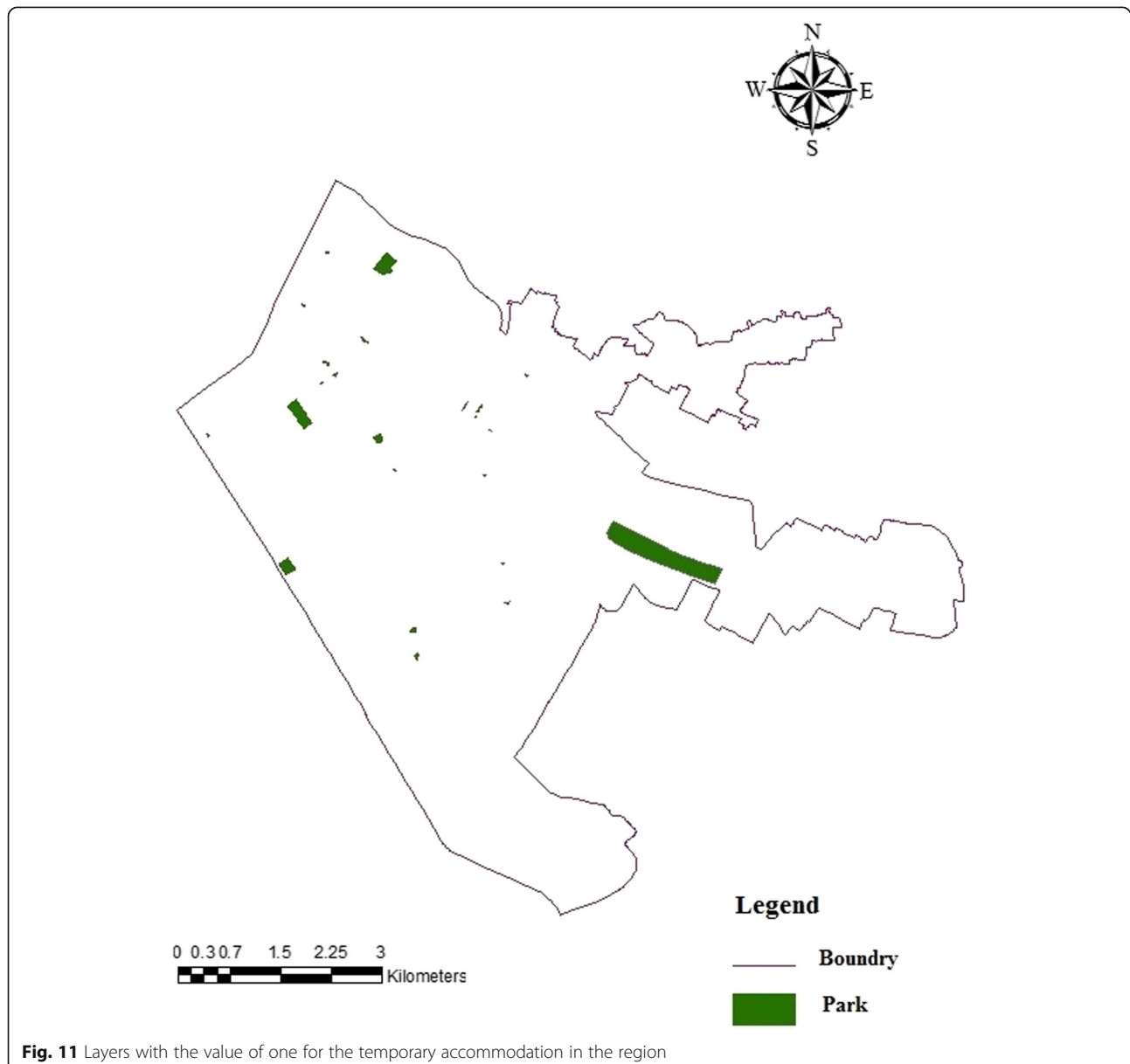
well as the optimal route based on each of the above indicators.

Results and discussion

Earthquake damages in the region buildings were determined by considering the faults in the region and using the instructions in HAZUS (Fig. 9).

Locating emergency accommodation

First, AHP was used to prioritize and optimize the parameters in two stages. MATLAB was used for AHP by investigating the adaptability of the experts' judgments and opinions, as well as the criteria



weights. Now, the calculations related to the selection of emergency accommodation in the studied region were presented.

The indices should be compared with each other in pairs in order to determine the indices of significant coefficients. The basis for judgment in this comparison was a 9-quantity table. Accordingly, the strength of me index compared with the j index was determined. Accordingly, n^n comparison was conducted for n parameter. In other words, considering the determined 11 major indices and 32 questionnaires, $11^{11} \times 32$ comparisons were conducted to determine the strength of the major indices in this study.

MATLAB was used to evaluate the judgments adaptability, which was conducted by forming matrices and using the related formulas. Studying the adaptability of the judgments in the matrices of paired comparison parameters suggested that compatibility was observed in the judgements as shown in Table 2 ($C.R. = 0.08725 < 0.1$).

Boolean two-dimensional logic model was used for locating in the study due to its valuing system. The location for constructing accommodation centers is either suitable or unsuitable due to the sensitivity of their functions as well as the nature of accommodation centers. In this model, the locations which are

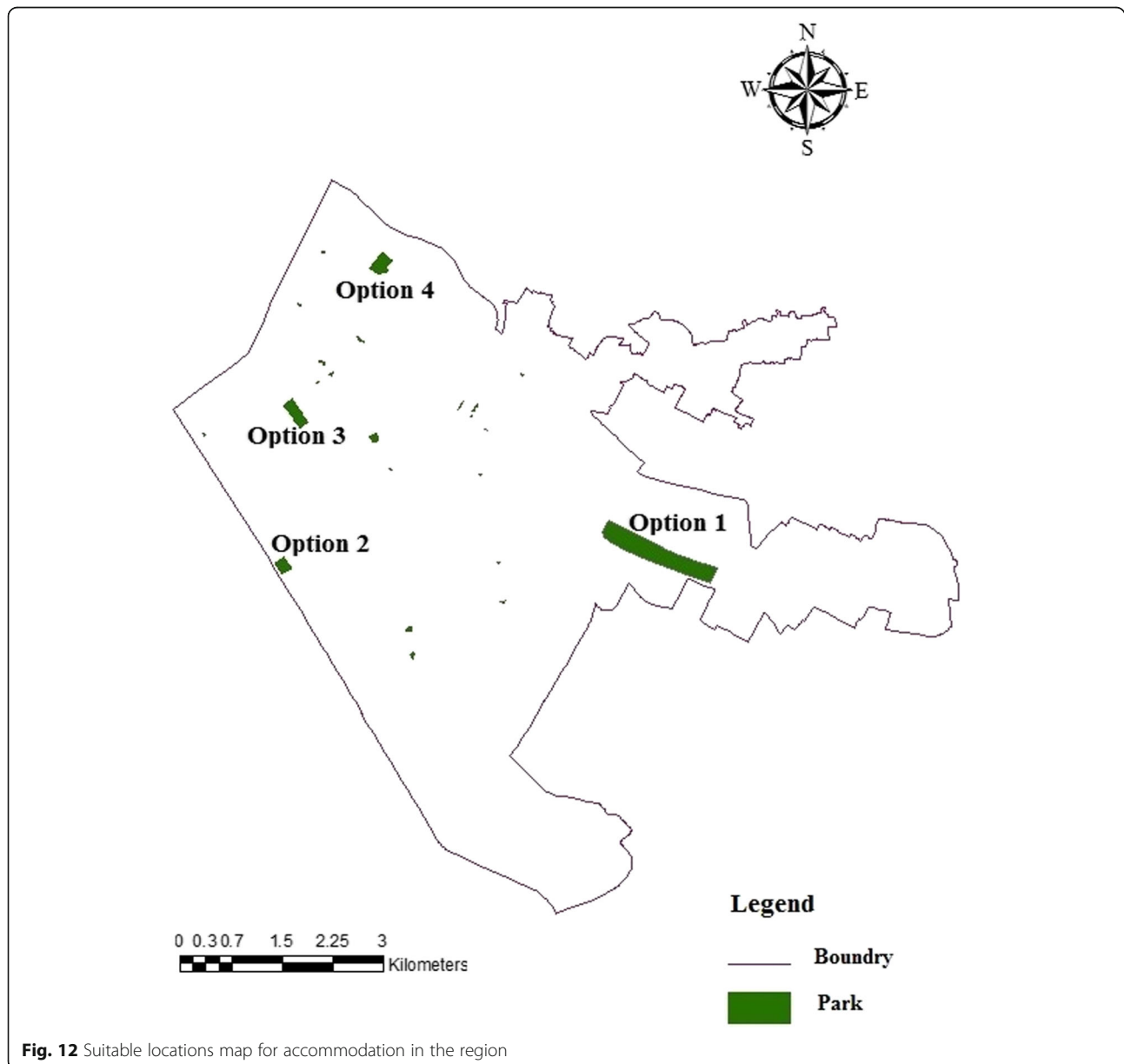


Fig. 12 Suitable locations map for accommodation in the region

not suitable based on the presented criteria are given zero and suitable locations are given one in this value system.

Step 1: Determining unsuitable sites by considering deterrent and limiting factors. In this step, the sites in the area of faults, fuel stations, and aqueducts which are not suitable for accommodation are identified. The results of this step are shown in Fig. 10.

Step 2: In this step, all suitable places for accommodation in the study area are identified. It should be noted that the sites are determined without prioritization. The results for suitable accommodation site are shown in Fig. 11.

Step 3: In this step, the most suitable places for accommodation are determined. At this step, suitable sites (without prioritization) are identified from all available sites which have the capability of emergency accommodation by using GIS and AHP, and considering the restrictions in the region. The result of this step is shown in Fig. 12.

Final score determination (priority) of the choices

In this stage, the final score of each choice was determined by combining and integrating the scores of

the parameters and the choices derived from the paired comparison matrices. To this aim, Sa'ati's principal of hierarchical composition was used and "priority vector" was derived by considering all the judgments in all stages of hierarchy. The ultimate weight of each choice was derived from multiplying the significant parameters in the choice weights (Figs. 13 and 14).

Figure 13 gives the effective criteria and sub-criteria in selecting the best accommodation from the 4 accommodation sites previously shown in Fig. 12. Further, Fig. 14 illustrates the numerical weight and effectiveness of each of these criteria and sub-criteria, which will determine the best accommodation sites by their prioritization.

The following formula was used for calculating the ultimate score of the choices.

$$\text{The ultimate score (priority) of choice } j = \sum_{k=1}^n \sum_{i=1}^m W_k W_i (g_{ij})$$

W_k = Significance coefficient of criteria K.

W_i = Significance coefficient of criteria i.

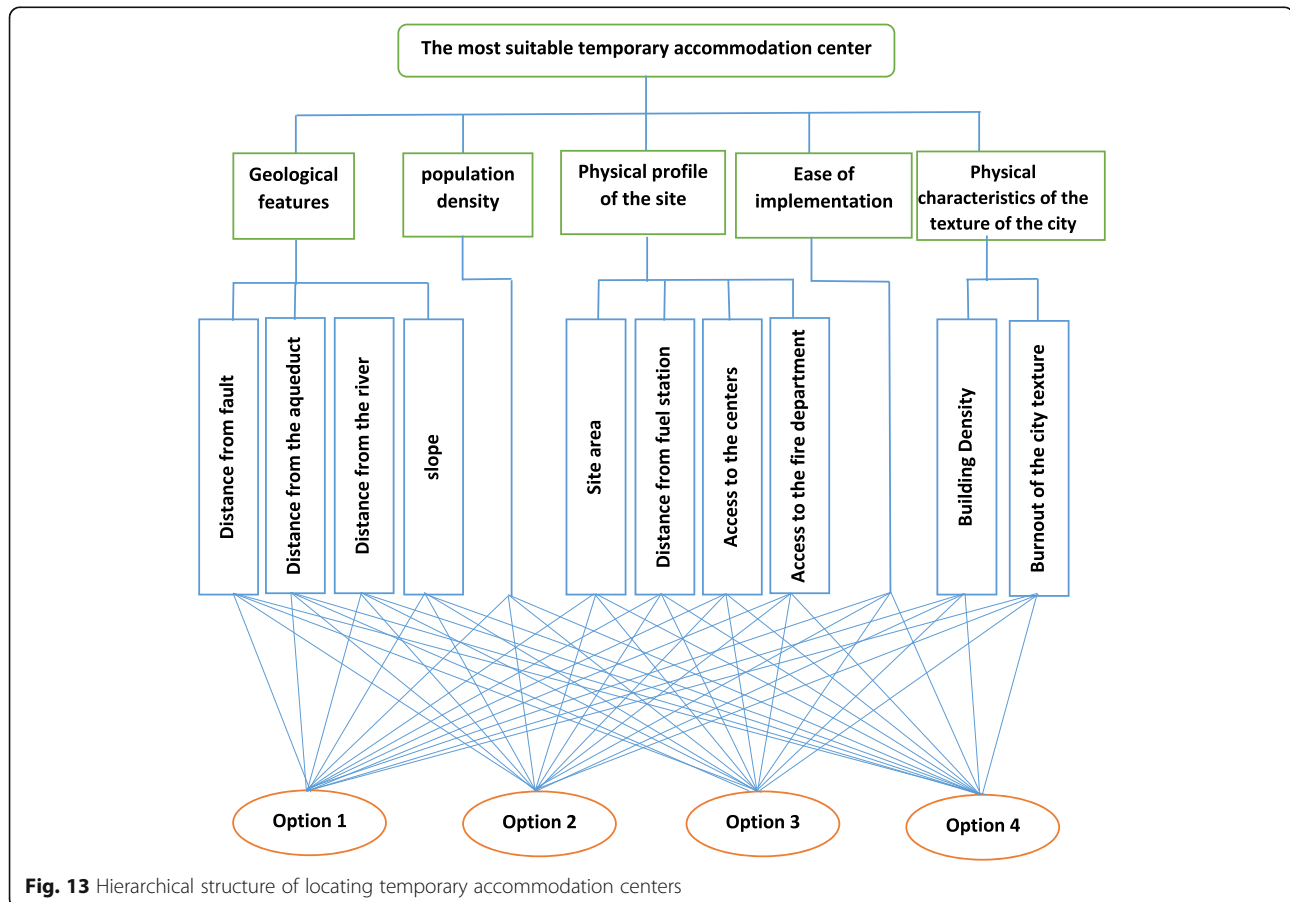
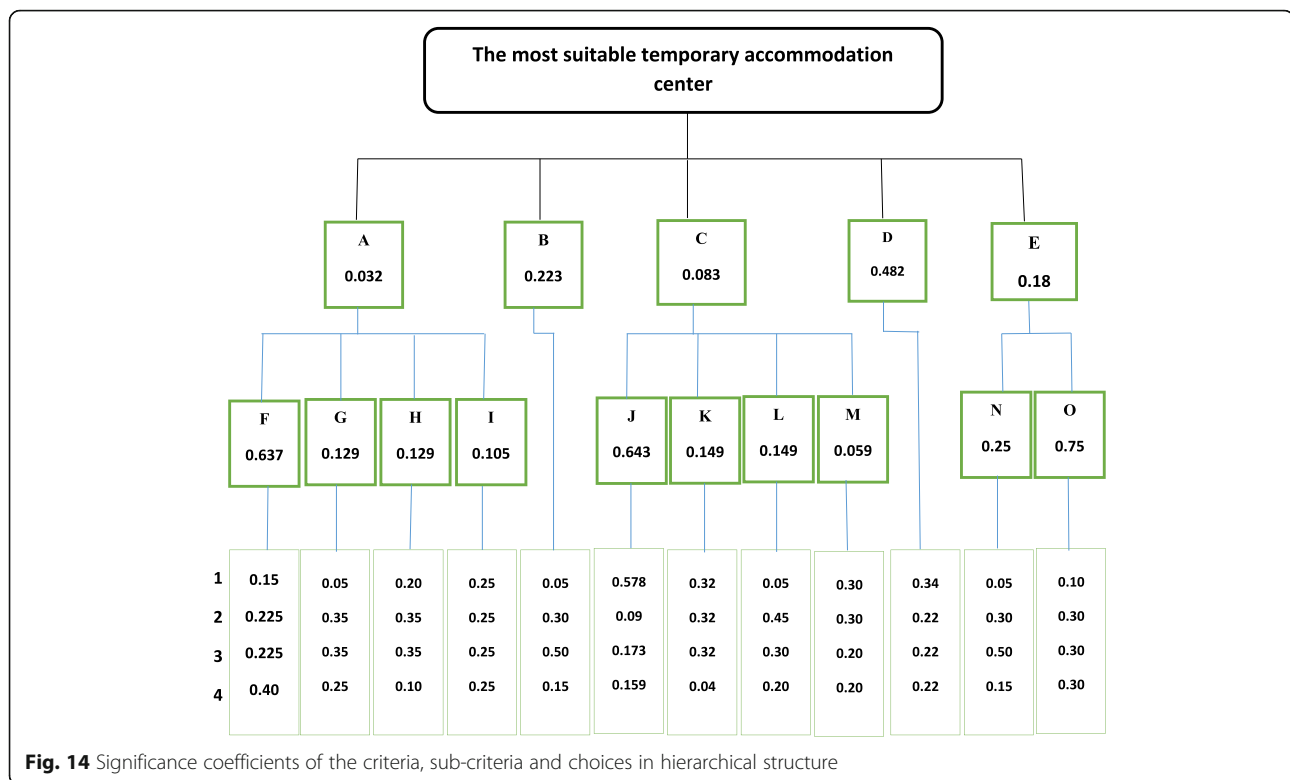


Fig. 13 Hierarchical structure of locating temporary accommodation centers



g_{ij} = Choice j score in relationship with the sub-criterion of me.

Considering the conducted calculations, the final score of the accommodation choices is as follows.

$$W_1 = 0.23268 \quad W_2 = 0.25135 \quad W_3 = 0.307085 \quad W_4 = 0.209874$$

Considering the results of Fig. 13, the best choice is the choices 3, 2, 1, and 4, respectively, as presented in Fig. 15.

Evacuation road determination

Weight calculation (significance coefficient) of the parameters

The AHP assessment method is considered as one of the multi-index assessment methods used in this study. This model consists of five main stages which are effective by applying quantitative and qualitative indices simultaneously, where several decision-making parameters can make the choice conditions difficult. The reason for hierarchical nature of the structure was that the decision-making elements (choices and decision-making parameters) should be summarized in different levels. Transforming a subject or problem into a hierarchical structure is the most important parts of AHP as presented in Table 3.

Calculating the significance coefficients of the main indices

Table 4 indicates the binary comparison matrix of the main indicators. Studying the numbers and significance coefficients were derived from the paired comparison of the main indices which indicated the relative significance of 62, 22, and 16% for safety, traffic, and road length, respectively. Tables 5 and 6 show the paired comparison matrix of the safety and traffic indices, respectively. Table 7 indicates the paired comparison matrix of the traffic indices.

Judgement adaptability survey

In the study, Expert Choice software was used to determine the adaptability of the judgments. Based on the results, adaptability was observed in the judgements for the main and secondary indices, respectively ($C.R. = 0.03 < 0.1$, $C.R. = 0.00307 < 0.1$).

Optimal road determination test based on the results derived from modeling safety index parameters

In this stage, the weight of each available road in the region was assessed based on the desirability and each sub-index was inserted in a table. Then, the written codes were defined to be considered as the basis. The algorithm and the model designed for optimal road determination followed a specific data structure and the data were used for the designed

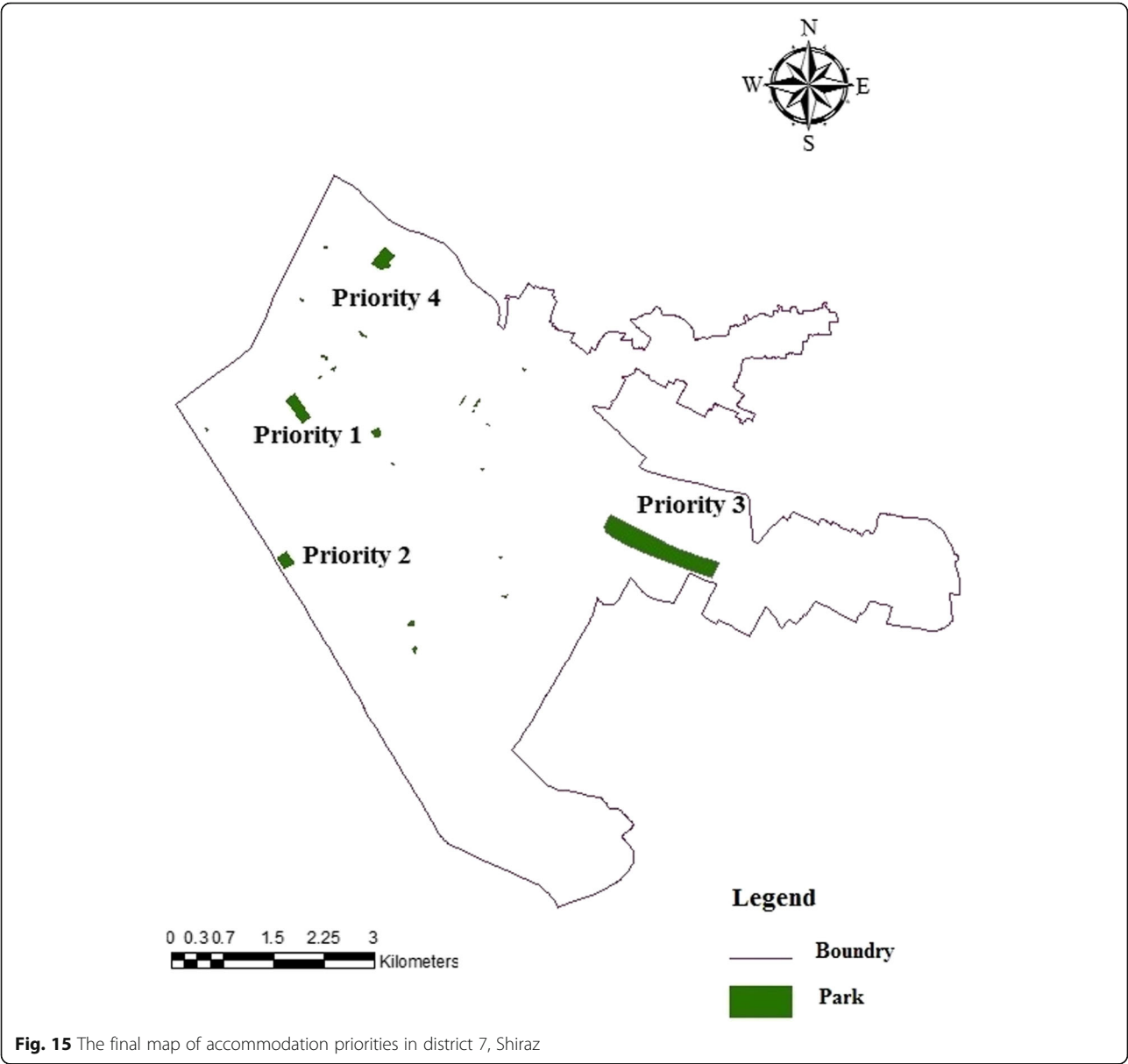


Table 3 AHP derived from experts' opinions to determine the effective parameters in emergency evacuation and relief paths

Goal (First Stage)	Determining the Parameters Influencing Emergency Evacuation and Relief Roads Determination		
Indices (Second Stage)	Safety	Traffic	Road Length
Sub-Indices (Third Stage)	Vulnerability of the Adjacent Buildings	Roads Network Width	Road Length
	Population Density	Volume of the Population on the Road	
	Transportation Construction such as Bridges		
	Dangerous Uses		
Choices (Fourth Stage)	1. Very Dangerous 2. Dangerous 3. Mild 4. Low Risk		

Table 4 Paired comparison matrix of the main indices

Index	Safety	Traffic	Road Length	Normalized	Significance Coefficient
Safety	1	2.941	3.664	2.209	0.62
Traffic	0.336	1	1.385	0.775	0.218
Road Length	0.27	0.722	1	0.58	0.163

Table 5 Paired comparison matrix of the safety indices

Index	Vulnerability of the Adjacent Buildings	Population Density	Transportation Construction	Dangerous Uses	Normalized	Significance Coefficient
Vulnerability of the Adjacent Buildings	1	2.503	1.837	1.395	1.591	0.376
Population Density	0.4	1	0.741	0.571	0.641	0.152
Transportation Construction	0.537	0.3507	1	0.758	0.861	0.204
Dangerous Uses	0.717	1.751	1.320	1	1.135	0.268

Table 6 Paired comparison matrix of the traffic indices

Index	Roads Network Width	Volume of the Population on the Road	Normalized	Significance Coefficient
Roads Network Width	1	1.752	1.323	0.637
Volume of the Population on the Road	0.571	1	0.756	0.363

Table 7 Significance coefficients of all indices effecting the emergency evacuation and relief roads determination

Index	Vulnerability of the Adjacent Buildings	Population Density	Transportation Construction	Dangerous Uses	Roads Network Width	Volume of the Population on the Road	Road Length
Significance Coefficients	0.233	0.094	0.126	0.166	0.138	0.079	0.163

algorithm and optimal road determination model by using the following features.

- Creating a matrix of the nodes including all network nodes containing road, blocks and safe regions by considering emergency accommodation and emergency evacuation places
- Providing the network structure in order to extract all the nodes related to any given node
- Creating a matrix for presenting the network nodes
- Creating a matrix for presenting the weight of the roads in the network

As it was already mentioned, the condition of the buildings adjacent to the road network and assessing their vulnerability, the influence of the Hazardous land use in the region, and the evaluation of transportation construction conditions and population density are

considered as the parameters with a high degree of significance from the experts' point of view which can affect the determination of the optimal relief and emergency evacuation road. Then, the optimal roads based on each index were operated on the road network of the studied region, the graph network of which are presented in Fig. 16, and the derived results are shown in Appendix. The routes which are presented in bold indicate the optimal roads based on the sub-indices of roads network safety for emergency evacuation and relief in district 7, Shiraz.

In these models, the node 17 was considered as the emergency accommodation place. Figure 17 shows the bold roads expressing the optimal roads based on the length for emergency evacuation in District 7, Shiraz. In other words, if the victims in the studied region like to reach node 17, the most optimal road is along the bold lines. In other words,

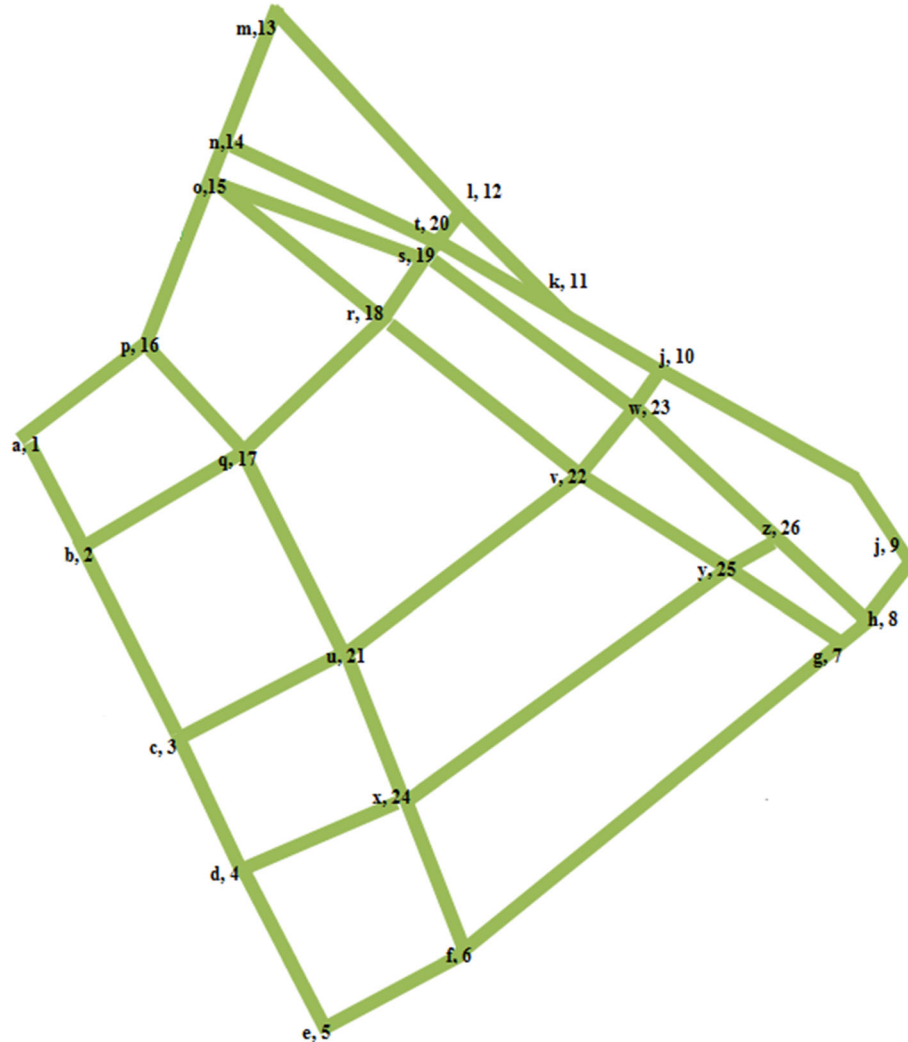


Fig. 16 Roads graph network in district 7, Shiraz

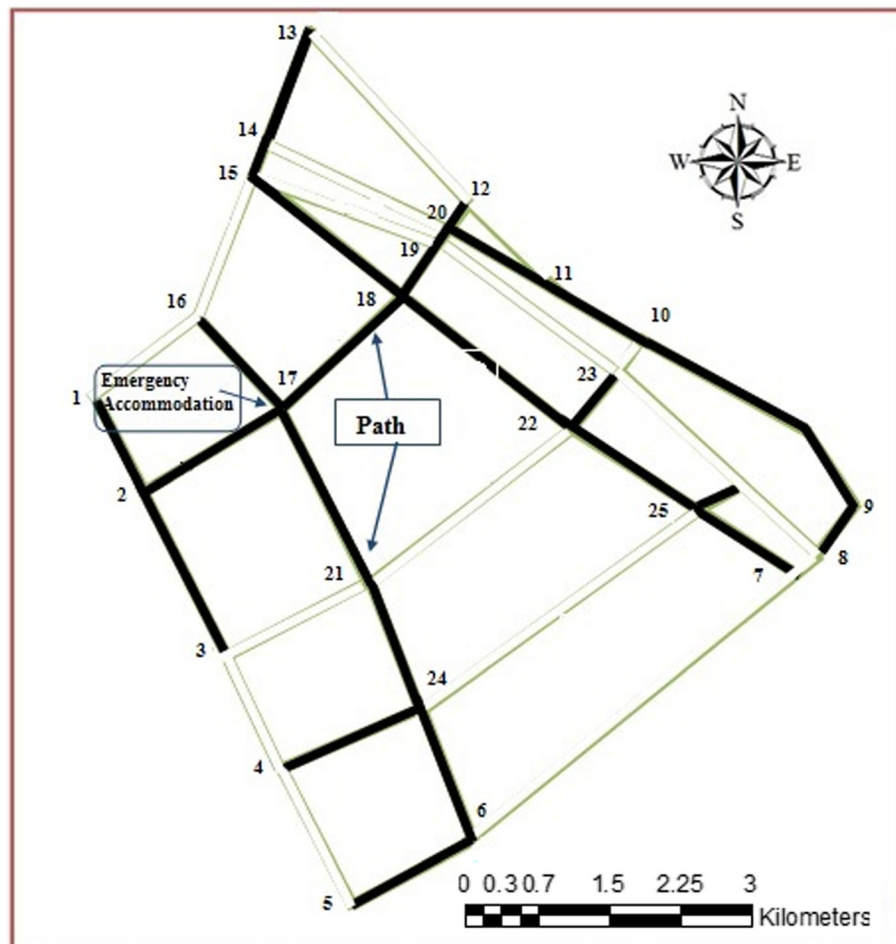


Fig. 17 Optimal road network for emergency evacuation in district 7, Shiraz by integrating all parameters

if the victims near the node 10 are interested in reaching the emergency evacuation place in the node 17, moving along $10 \rightarrow 11 \rightarrow 20 \rightarrow 19 \rightarrow 18 \rightarrow 17$ is the most optimal road based on the length.

Conclusion

Preparation before crisis is considered as one of the most important issues in cities which has attracted the attention of urban planners. In this study, the conditions of District 7 of Shiraz were evaluated and attempts were made to present proper areas for creating temporary accommodation site and evacuation roads by considering the strengths, weaknesses, opportunities, and threats in the form of present usages and infrastructures since predicting the places for temporary accommodation and their connecting roads is one of the main issues after earthquake. In addition, determining the emergency accommodation places is useful while determining

safe and optimal access roads from different areas of the city. Otherwise, it can increase the traffic congestion on the roads and can play a negative effect on relief process. Further, the damage analysis of the buildings in the region is regarded as one of the important indices in this issue which should be determined carefully. Thus, the emergency accommodation places and optimal access roads were determined from different parts of the city in this study.

Based on the conducted studies, safety, traffic, and road length with 62, 22, and 16% were the most influential parameters in emergency evacuation roads to the emergency accommodation, respectively. Safety parameters include building vulnerability, population density, transportation constructions, and hazardous land use, while effective parameters on road traffic are road width and population density on the road.

Appendix

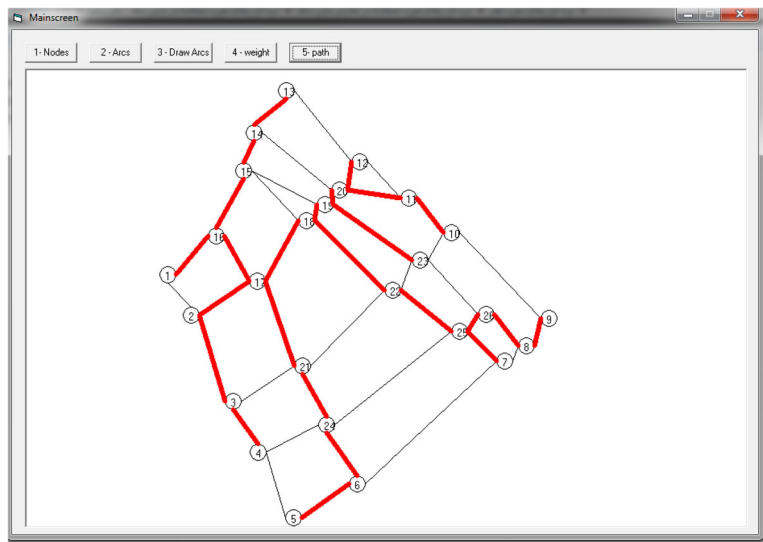


Fig. 18 The Results Derived from Implementing the Model of Roads Length Index on the Sample Data

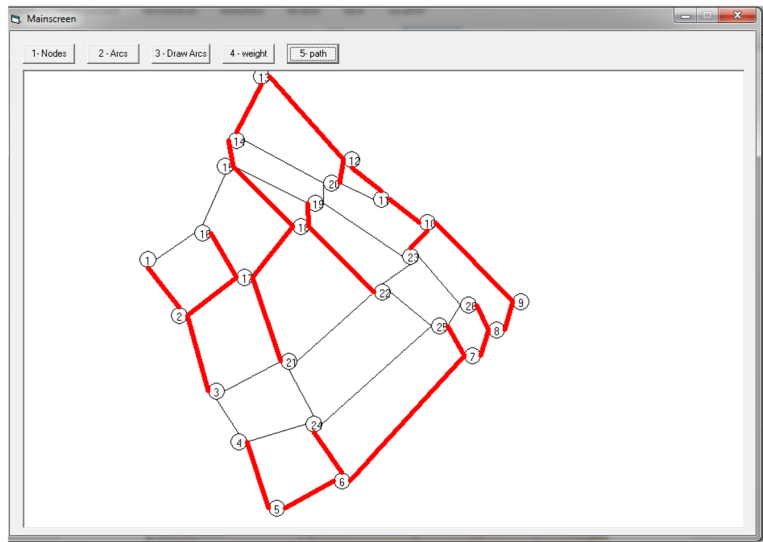


Fig. 19 The Results Derived from Implementing the Model of hazardous land Uses Index on the Sample Data using Software

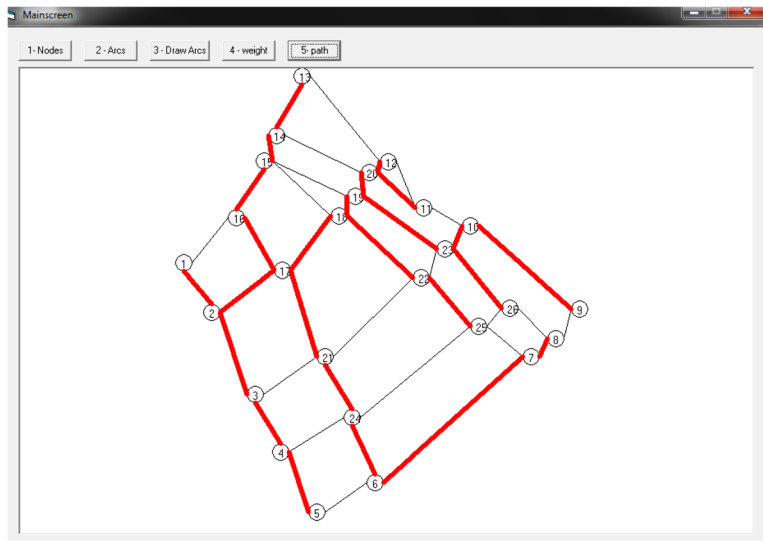


Fig. 20 The Results Derived from Implementing the Model of Transportation Constructions Index on the Sample Data using Software

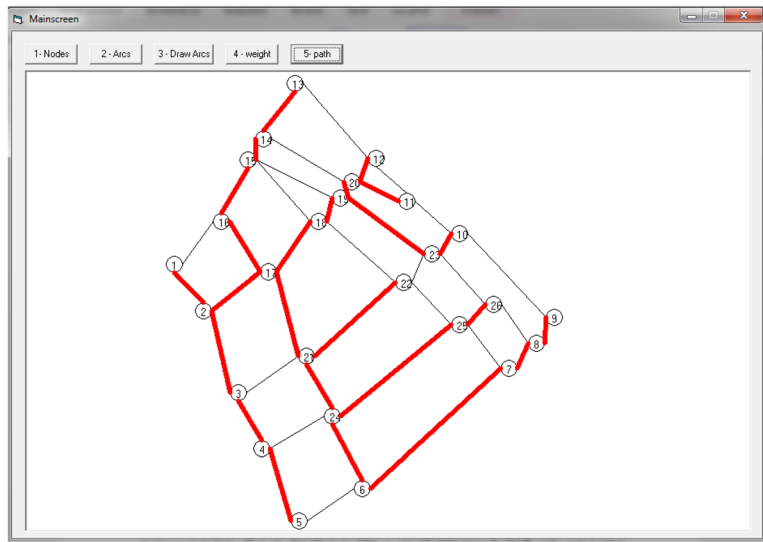


Fig. 21 The Results Derived from Implementing the Model of Population Density Index on the Sample Data using Software

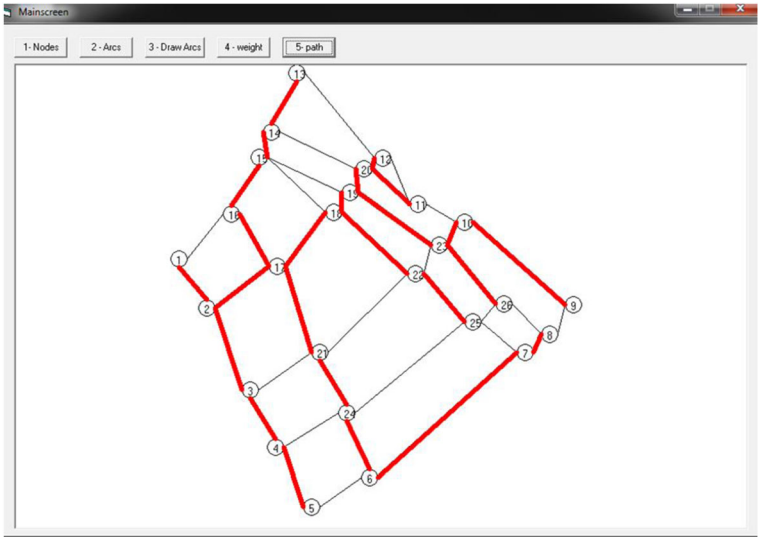


Fig. 22 The Results Derived from Implementing the Model of Buildings Vulnerability Index on the Sample Data using Software

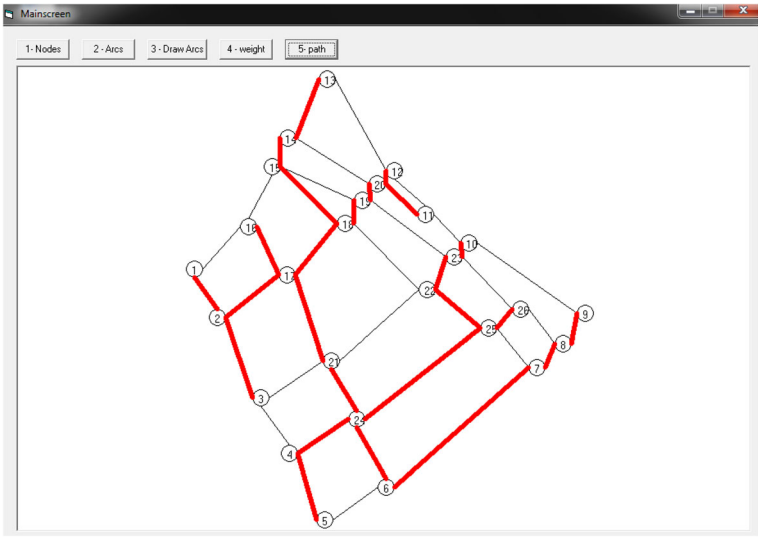


Fig. 23 The Results Derived from Implementing the Model of Safety Index on the Sample Data using Software

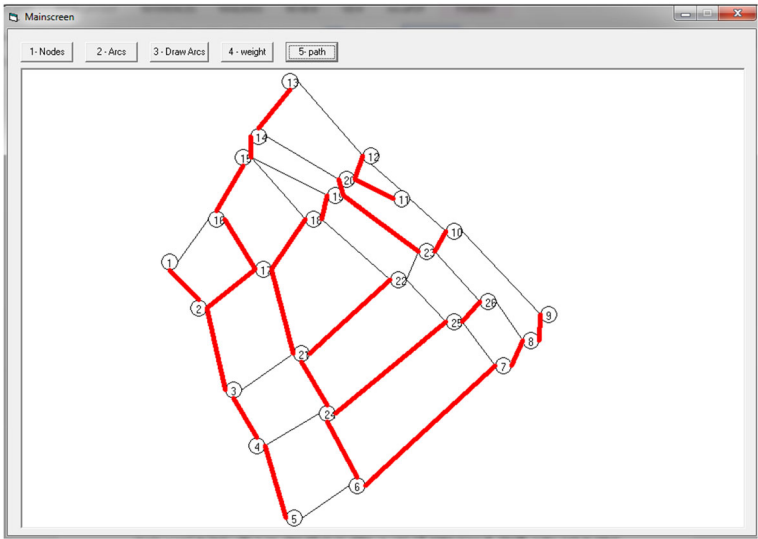


Fig. 24 The Results Derived from Implementing the Model of Volume of the Population on the Road Index on the Sample Data using Software



Fig. 25 The Results Derived from Implementing the Model of Main Indices on the Sample Data using Software

Abbreviations

AHP: Analytische Hierarchie prozess; FEMA: Federal Emergency Management Agency; CDPC: Central Disaster Prevention Council; GIS: Geographic Information System; VC++/Visual C++

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Authors' contributions

KNK designed the project, data analysis, contributed to writing and reviewing the paper. SG did the field work, data analysis, contributed to writing and editing the paper. The author(s) read and approved the final manuscript.

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Availability of data and materials

All data, models, or code generated or used during the study are available from the corresponding author by request.

Declarations

Competing interests

There is no competing interest.

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