Comparing the Accessibility of Rescue Centers in the Districts of Tehran Municipality after Catastrophic Earthquakes

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Abstract

In this research, the centers involved in relief operations in Tehran traffic area districts have been compared and the supply-demand ratio has been specified through a relation presented separately for each district. The supply has been evaluated based on three parameters: 1) No of relief centers, 2) congestion of the main road (the ratio of the length of the main road to the area of the district), and 3) the ratio of the length of the main road to those of the secondary roads. The demand has been considered based on the number of casualties waiting for relief per unit area of each district.

After delimiting the districts in the case study and extracting the network's populations and roads information layers in the GIS, two road classes were specified: 1) main roads (capable of working under disaster conditions) and 2) secondary roads (capable of obstructing relief operations in needy areas). Next, the parameters were co equalized with their corresponding maximum values and scaled in the 0-100 range. The final results have been shown separately for each district (totally 32 in number) as the accessibility index. Accordingly, districts with indices smaller than 2 are considered as weakly accessible and those with indices more than 15 as properly accessible; districts with indices 2-8.5 have average accessibility.

Keywords: earthquake, accessibility, relief, transportation, district .

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1. Introduction

Relief operations and accessibility (of the victims and injured people) to medical centers are important issues always raised by the authorities and those involved in the disaster management to minimize the earthquake fatalities. The more are the distressed zones (congested, old buildings, low quality construction materials, narrow roads and passages that do not comply with the roads hierarchy, and so on) in a district, the more will be the district's vulnerability. According to the existing statistics, there have been 1303 earthquake incidents which caused 800(b $) losses in the world during 1990-2015; the information of the world's five serious earthquakes during 1980-2009 Iran has been the five most natural disaster prone country. The 1990 Manjil–Rudbar earthquake killed approximately 40,000 people, left more than 500,000 homeless and 8 (b $) in the affected area. The last catastrophic earthquake in Iran occurred in 2003 which killed 28000 people, left 300,000 homeless and 512(m $) losses in affected area. After an earthquake, many changes will occur in the supply, demand, and traffic management system considering the intensity, time, and location of its occurrence. Changes in supply will lead to a reduction in the capacity of arcs and an increase in the demand which makes the choice of the effective route difficult. These changes, collectively, affect the travel time which is determining in the preservation of the victims and injured people's lives. Connection between the origin (which can include the affected areas) and destination (which can be medical centers) is quite determining; therefore, the availability of at least one origin-destination route is vital and the more is this route capable of passing traffic in a time limit of 72 hours after an earthquake, the better it will perform. Accordingly, the more are the arterial (high performance) roads, the better will be the relief, and the more is the length of the secondary roads, the more difficult will be the disaster management and relief operations (because of the probability of more traffic congestion and less permeability).After an earthquake, the internal trips between different areas and districts increase considerably and the traffic becomes congested in all directions due to a rapid increase in the demand in a very short period of time. Under such circumstances, the road capacity drops more, compared with the normal conditions, because of the drivers' behavioral disorder (hostile, aggressive, and anxious behavior). This analysis is used for a municipality to measure its application in regard with resilience increasing policies in Tehran (Attention to empowering communities in district scale and the people's participation in disaster management). Therefore, when the number of rescue centers and facilities is determined in each district, the level of district's preparation against probable disasters is also specified for decision makers which follow financial savings for disaster management. This approach is useful in future planning for health centers, transportation network and other facilities based on the risk in each district. Also physical planning and human population of each district and their sectors can be considered. The paper is organized as follows: Next section provides a review of the literature on Road network performance after disasters, while Section 3 describes case study and data collection of study area. Section 4 is the methodology and data analysis. The last section discusses our conclusion and sets future study

2. Literature Review

In this section, we review the related literature on the road network performance and post-earthquake relief operation. The study of Giovinazzi and Nicholson showed after an earthquake, the new origin-destination travel distribution patterns during different time periods are different based on the following:

1- The extent the residential and service buildings (schools, offices, etc.) have been damaged.

2- Settling people in temporary, emergency settlement camps.

3- More accessibility needed by service centers (hospitals, medical centers, etc.).

4- The need to rescue people in the form of physical transportation in the affected areas.

5- People's tendency to recede and avoid the risk of more damage conditions. They presented four indices for the evaluation of the transportation network performance; as follows:

- Connection reliability index: it indicates the probability of the arc nodes connection and the traffic capability of reaching the desired destination.it used in emergency management phase.
- Capacity reliability index: it indicates the probability if the transportation network is capable of meeting the demand at different service levels. It used in response management phase.
- Travel time reliability index: it indicates if reaching the destination is possible in less time than certain specified limits. it used in recovery management phase.
- Accessibility reliability index: it indicates if the transportation facilities are capable of making possible reaching the desired destinations in appropriate time periods; it used in recovery management phase [Giovinazzi and Nicholson, 2010]

In another effort Wakabayashi and Lida have shown that the travel matrix after an earthquake gets bigger about 28% compared with the one before and the travel time increases about 30%. These and other changes caused by the road body damage and also by the structural, non-structural, and managerial components of the relief centers and organizations severely affect the transportation system balance [Wakabayashi and Lida, 1992]. Taylor et al. presented an index of the change of the total time cost of a arc before and after the disaster as follows:

$$Ta = \sum_k qk.\Delta Cka \quad (1)$$

where $\Delta Cka = Ck - \hat{C}ka$ is the total cost change for k origin-destination pairs caused by the destruction of arc a, Ck and $\hat{C}ka$ are respectively indications of the least route costs before and after the destruction of arc a, and qk is the demand governing k origin-destination pairs[Taylor et al.2006]. Nagurney and Qiang proposed the following relation for the efficiency measurement of a Network topology index:

$$\varepsilon(G,Q)=\sum_k \frac{q_k}{Ck.nk} \quad (2)$$

Where the parameters are as in Relation (1) and nk is the number of origin-destination pairs in network with topology G and origin-destination demand Q. This relation shows the average number of trips for a unit cost and the network efficiency in terms of the traffic-to-cost ratio [Nagurney and Qiang, 2007].Scott et al. showed the network robustness index (NRI) in relation to selecting the substitute route as follows:

$$NRI=\hat{C}a-C \qquad (3)$$

Where $\hat{C}a$, C are travel time cost after and before route destruction respectively. This relation measures the changes of the travel time cost throughout the network caused by selecting a substitute route because of assumed total route destruction and compares it with that of a case where all routes are usable. Here, when a route gets closed, drivers use the route user balance law for substitute routes. The travel cost is found as follows:

$$C=\sum_s t_s . x_s \qquad (4)$$

where ts and xs are respectively the travel time and traffic flow in arc s [Scott et al.2006]. Balijepalli and Oppong considered serviceability index which is the possibility of using a road in a specific time period; it may cause a drop in the road performance quality.in this research presented the network vulnerability index (NVI) as follows considering the arc serviceability and the possibility of a change in a route all or part of which has been destroyed:

$$NVI=\sum_{i=1}^{|A|}\left[\frac{xi}{ri}.ti\right] - \sum_{i=1}^{|A|}\left[\frac{xi}{ri}.ti\right] \qquad (5)$$

where ri is arc i serviceability potential found through dividing the total accessible capacity (sum of the capacities of the operating accessible lines) by the standard hourly capacity of each route in this arc, xi and ti are respectively the traffic flow and travel time in arc I, and |A| is the number of the network elements [Balijepalli and Oppong, 2014]. Eun Su Lee presented a new approach for analyzing the potential of accessibility to ambulance services through combining the rate of the met demand and the serviceability potential rate covered by the ambulance. He used the spatial analysis-based GIS for the ambulance service designers and planners so that the service coverage rate can be found based on the simulated stochastic occurrence. He evaluated in his model (capable of being used at the regional and provincial scales), the accessibility and serviceability of some specified locations considering the residing households and the travel time. The accessibility potential index (Az) and the serviceability index (Sj) are respectively found as follows:

$$Az=\frac{t0^z}{T_Z} \quad , Tz=\frac{\sum tji}{Ni} \qquad (6)$$

$$SJ=\frac{t0^J}{T_J} \quad , Tj=\frac{\sum tji}{Ni} \qquad (7),$$

$$\frac{\sum tji}{Ni}$$

where tji is the shortest travel time from the position of the ambulance j to the incident location i, Ni is the number of events in zone z, $t0^z$ is the reaction time designed for this zone, and $t0^j$ is the suggested reaction time considering the average reaction time of the ambulance at position j [Eun Su Lee , 2014]. After an earthquake, relief is the most important measure to take; relief operations are to be organized and carried out in the shortest possible time. America's Caltrans (California Transportation System) enumerates the relief operations as: 1) people safety, 2) plants, facilities, and installations' protection and preservation, and 3) transportation system's quick reopening [Caltrans, 1994]. JICA has defined the emergency relief operations under the following four cases:

1) No relief, whatsoever.
2) Public relief: people not entrapped will help those entrapped using their hands and some simple tools.
3) Public relief + relief groups: in addition to the public relief, the Red Crescent Society and the Fire Fighting Department to participate in relief operations. These operations are orderly and use is made of some machinery (tower cranes, loaders, etc.) and devices (chainsaw).
4) Public relief + relief groups + professional help: besides the above mentioned operations, some specialized people and emergency relief groups from other places (including foreign countries) join the operations; optical fiber cameras, aid dogs, and other special devices and instruments are also used[JICA, 2000]. Studies of different researchers show that the transportation system performance in post-earthquake conditions is concentrated on the realization of one of the following objectives each of which is measured by an index; most accessibility indices are to achieve these goals:
1) Minimizing costs (trip, inventory, or both combined) which Huang et al.-Mete et al. presented [Huang et al.-Mete et al.]
2) Minimizing unintended demands which Rawls et al.-VanHentenryck et al. presented [Rawls et al.-VanHentenryck et al.].
3) Minimizing the due time of the last injured person which Nolz et al.-Hsueh et al. considered [Nolz et al.Hsueh et al.].
4) Minimizing the reaction time which Lin et al.-Shen et al. mentioned [Lin et al.-Shen et al.]. Recently regard of the disaster type, severity, losses and demand quantity, identification of critical routes considered as a separate research. To see uncertainty in disaster, sometimes Stochastic approaches was used.it can be found in Mohamadi and Yaghoubi, Babaei et al.Alinezhad et al.Tavakkoli-Moghaddam et al.. [Mohamadi - Yaghoubi, 2017], [Mohsen Babaei et al.2017],[Alinezhad et al. 2017], [Tavakkoli-Moghaddam et al. 2016].
Effort has been made in the present research to study the transportation network performance in providing service to probable casualties/victims and transferring them to medical centers.

3. Study Area

Tehran central restricted zone (Figure. 1) covers the major parts of regions 11 and 12 and some southern parts of regions 6 and 7.

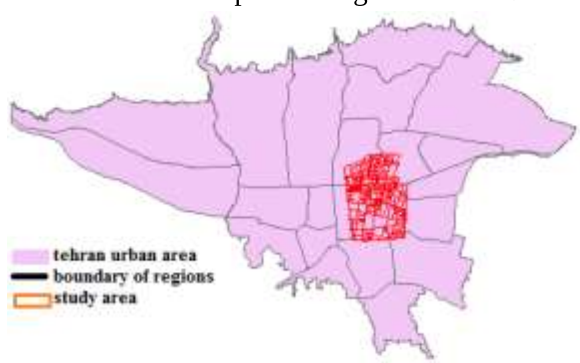

Figure 1. Tehran central restricted zone

This area contains 46 medical centers, 41 ambulances, and 12 firefighting stations which would face very many casualties and victims in case an earthquake occurs. At present, these medical centers, with an average capacity of 94 beds each, can bed a maximum of about 4300 people. Considering the traffic congestion, present worn out tissues, limited capacity of the medical centers (that will face increased demands due to the created shock), and the roads capacity drop (caused by blockages), relief operations will be of utmost importance to prevent fatalities to soar 72 hours after an earthquake. Since Tehran central restricted zone covers the city’s business district, some limitations were imposed to control the public vehicles' accessibility and regulate the traffic flow in this part of the city. These were first imposed in the middle of 1979 to give priority to Vahed Company's public busses for easier movement in different streets. Next, the single-crew cars and then all vehicles except public, rescue, military, and diplomatic cars were banned to enter the mention area; a limited number of cars could commute in the area for one year on toll payment. These limitations are still valid and applied from 6:30 to 17 every day except holidays in an area of about 3174 hectare.

Studies have shown that there are about 203355 shuttling in the central restricted zone which is 21% more than the allowable capacity. Despite these limitations, the traffic movement in this area is quite slow during most weekdays because of high concentration of traffic absorbent activities and places such as shopping centers, Tehran Bazaar, stock exchange office, and different administrative and political applications. Table 1 shows the traffic indices in the morning peak hours in regions 6, 7, 11, and 12 (main regions involve the central restricted zone); these indices have been found based on the weight average (area of each district).

Table 1. Car-equivalent traffic indices for central restricted zone and its vicinity during the morning peak hours [TCTTS and authors, 2015]

Area	Ave. speed (km/hr)	% Delay in total trip	%Slow & critical	%Excess road capacity
Region 6	14.5	70.4	53.8	23.8
Region 7	16.7	66.7	53.5	24.5
Region 11	13.1	71	61.8	25.7
Region 2	10.9	75.1	63.5	27.1
Case study area	13.8	70.8	58.1	25.6
Tehran municipality	25.4	53.8	33.0	13.3

As shown, the average speed in the central restricted zone is half that of Tehran city and the streets in this area receive cars twice as much as their true capacities. A comparison of the indices shows that the central restricted zone has unacceptable conditions compared with the entire city. It is obvious that under such critical conditions as earthquake, this chaos can be far more severe.

The population of the central restricted zone is 527000 (nearly 175 people/hectare) [SCoI, 2016] which is 6.5% of the total population of Tehran.

Considering the performance of the districts under critical conditions, the central restricted zone has been divided into 32 districts with an average area of about 100 hectares. The average population density is 204/hectare with the highest density belonging to the southern and some northeastern parts of the central restricted zone.

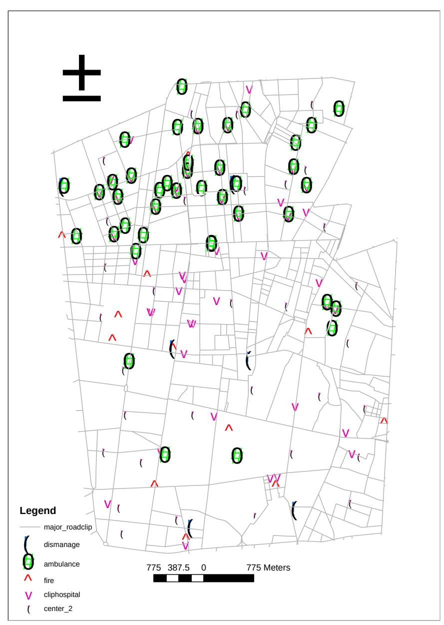

Figure 2. Districts, hospitals, ambulances, disaster management centers and firefighting stations in case study area

The important issues in studying the transportation network performance in the area being studied are the situation of the roads and passages, their degree of performance, and their level of service; unfortunately, Tehran Highways Network has not been included in the central restricted zone. The existing roads can be of two classes: 1) main streets which are reliable under critical conditions and 2) secondary roads including dead-ends and alleys which are not only unreliable, but they are also very difficult to penetrate into because they are quite narrow and hard to close entirely or partly. Out of 819 km of all types of streets and roads, more than 509 km (almost 62%) have widths less than 5 m which are not reliable under critical conditions, about 17% are 6-10 m wide, almost 20% are 11-20 m wide, and the rest have widths more than 20 m; in 2-way streets, the width of only one way has been considered.

The road density (length per hectare of the district area) shows that on average there are about 65 m/hectare of main roads and 134 m/hectare of secondary roads in the central restricted zone; the highest densities of the main and secondary roads in the central restricted zone belong respectively to districts 24, 22, 14, and 26 (in the north) and 19, 11, 14, and 24 (in the south) which are all very hard to have access to in relief operations.

Traffic flow, which is a function of travel time and traffic volume, is a parameter that should be studied. After an earthquake and the changes in the capacity of roads (they get fully or partly closed), this function varies differently. The travel time-traffic volume functions that determine the delay time (in Tehran traffic central restricted zone roads) are shown in Table 2 for two classes of main and secondary roads assuming that the minimum travel time is a determining and decision making factor for a vehicle driver. Considering the demand shock and capacity drop (when saturation demand is doubled and capacity remains fixed), the travel time in the main and secondary roads increase respectively 5 and 13 times.

Table 2. Capacity and travel time-traffic volume function for main and secondary roads in Tehran traffic network [TCTTS, 2008]

No	Road class	Capacity (car/hr/1m width)	Travel time function
1	Main	305	T=1.4$\left[1+0.21(\frac{V}{305})^{4.7}\right]$
2	Secondary	180	T=2$\left[1+0.7(\frac{V}{180})^{4.9}\right]$

T is the average travel time (in minutes) for covering 1 km of the road length, V is hourly volume (car/hr/1m width)

Considering the fact that Tehran is surrounded by active faults, and there will be much destruction in case an earthquake occurs, Rey fault has been studied as the most serious and threatening seismic risk for the area being studied. The south and north Rey faults extend (almost parallel) in the direction of the southern and northern parts of the Rey subsidence respectively. The distance between the two faults, which are the most prominent in Tehran south plains, is only 3-5 km and they scatter throughout both sides of the subsidence. The last related event dates back to the year 855 and no significant seismic activity has been reported in the last 1000 years. Based on the GIS spatial information, a probable earthquake in this area (Figure. 3) will be of level 5 intensity defined based on Mercalli Scale

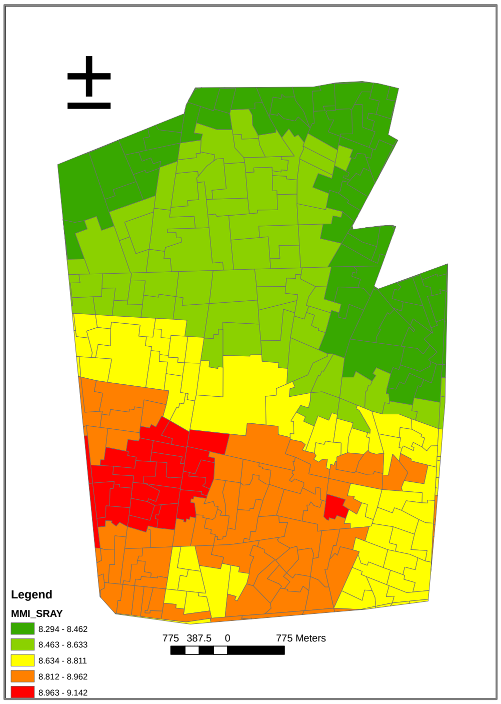

Figure 3. Earthquake hazard zoning in Tehran central restricted zone based on the Modified Mercalli Intensity Scale

The zone in the southwest of this area is more susceptible to earthquake hazards (due to soil genus); then, going from south to north, the hazard lessens because the distance from the fault becomes less. This is despite the fact that the population is more and the residential buildings' vulnerability is also more in the southern parts because of the old and worn out tissues. Fatality rates in regions 6, 7, 11, and 12 (major constituents of the area under investigation) are respectively 20.1, 14.7, 4.6, and 3.7%. In the meantime, around 42000 buildings (about 8.7% of those in the entire city) are situated in the area being studied. Table 3 shows the daytime and nighttime fatality rates for Tehran traffic central restricted zone under four relief situations. As shown, if relief operations are timely and sufficient, fatality rates will drop 50% or so.

Buildings spatial precision and other features were collected from Tehran Prevention and Disaster Management Organization. Using this information, we were able to prepare the information layers of different sections in an integrated form with the GIS format. The number of fatalities in an affected building will depend on its type, its destruction pattern, and the story used; the building type itself is a function of its constituent materials, structure (steel, concrete, masonry, etc.), age, etc.

Figure. 4 shows the traffic central restricted zone situation based on four general building categories (Steel, RC, Masonry, and Adobe); as shown, Masonry has the highest share (almost 68%).

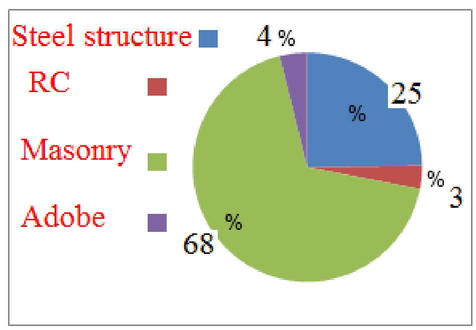

Figure4. Destruction of the buildings in the traffic central restricted zone according to their types

Figure. 5 shows the same, but based on the building height (number of stories): short (1-3 stories), medium (4-7 stories), and tall (more than 7 stories); as shown, more than 85% are short buildings.

Table 3. Fatality rates estimation for Tehran and case study -Rey fault model [JICA and authors]

Region	Nighttime				Daytime				Population
	Relief type				Relief type				
	1	2	3	4	1	2	3	4	
	Killed	Killed	Killed	Killed	Killed	Killed	Killed	Killed	
6	6517	5335	3814	4431	3879	3175	2864	2635	209704
7	12817	10592	9688	9053	7432	6142	5618	5249	276809
11	31635	27175	25560	24549	15269	13108	12324	11832	215160
12	37058	32747	31234	30344	18631	16461	15697	15247	184325
Case study	58954	49345	45663	43267	30780	25736	23791	22519	497923
Tehran	382822	320424	296518	280958	199876	167121	154490	146229	6359055

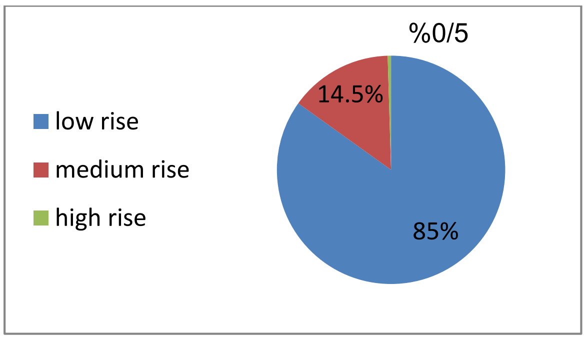

Figure 5. Destruction of the buildings in the traffic central restricted zone according to their heights

Figure. 6 shows the same, but based on the construction quality (age): low quality (built before 1976), average quality (built 1976-1996), and good quality (built after 1996); as shown, average quality has the highest share

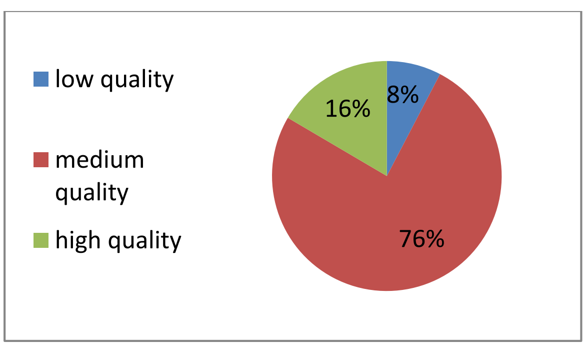

Figure 6. Destruction of the buildings in the traffic central restricted zone according to their construction quality

Using the earthquake-caused damage/fatality evaluation methodology presented in HAZUS and also the experiences gained in the recent severe earthquakes in Iran (e.g. Bam), the semi-experimental model was localized for Iran. Relation 8 gives the number of fatalities, the injured, and the healthy according to the number of buildings and the population inside. A very important parameter in this relation is the matrix of the coefficients of fatalities. It is to be noted that this matrix has been found separately for all types of buildings (totally 27) in Tehran

$$\begin{bmatrix} D \\ I \\ U \end{bmatrix} = \frac{P}{B} \times \begin{bmatrix} \alpha1 & \alpha2 & \alpha3 \\ \beta1 & \beta2 & \beta3 \\ \gamma1 & \gamma2 & \gamma3 \end{bmatrix} \times \begin{bmatrix} A \\ B \\ C \end{bmatrix} \qquad (8)$$

where D, I, and U are respectively the number of fatalities, injured, and healthy people, P is the building population, B is the number of buildings, α1, α2, and α3 are respectively the number of fatalities, severely injured, and outpatients in low destruction status, β1, β2, and β3 are the same, but in the medium destruction status, $\boldsymbol{\gamma}$ 1, $\boldsymbol{\gamma}$ 2, $\boldsymbol{\gamma}$3 are the same, but in the severe destruction status, and A, B, and C are respectively the number of undestroyed, half-destroyed, and totally destroyed buildings; the elements of the presented 3×3 matrix are those given in Table 4.

Table 4-Fatality coefficients matrix [TDMMO, 2010]

Destruction status	Fatality	Severely injured	Outpatient
Low	α1	α2	α3
Average	β1	β2	β3
Severe	γ1	γ2	γ3

In this research, since we needed to compare the districts' relative accessibility and did not need to find the fatalities separately for each building, for injured people Considering the results of previous studies based on demographic changes, updated information was used.

4. Methodology Proposed for Performance and Accessibility

The model proposed in this paper (Relation 9) is a function that somehow shows the supply and demand at the district level so that the comparison of the transportation accessibility of each district becomes possible. Accordingly, the number of centers (A) (hospitals, emergency departments, firefighting stations, disaster management centers, etc.) involved in relief operations in the district or 1 km from it, whichever is more, the density of the main roads length per unit area of the district (B), and the ratio of the main to secondary roads (C) are the supply parameters; demand is evaluated using the number of the injured. The method used in the present study was based on flowchart figure7.

After preparing the data bank, districts delimiting was done in the GIS environment using the related maps, all the data were evaluated and analyzed at the district level, and the necessary parameters were found. It is worth noting that the final function was found in terms of demand-to-supply ratio and classified under three categories.

$$AI=\frac{A+B+C}{D} \qquad (9)$$

where AI is the district accessibility level, A, B, and C, are defined before, and D is the difference between the injury cases under two conditions of no relief and public relief + rescue groups specified (considering the population and location) taken from Table 3. Results of the evaluations of all the parameters are presented in Table 5.

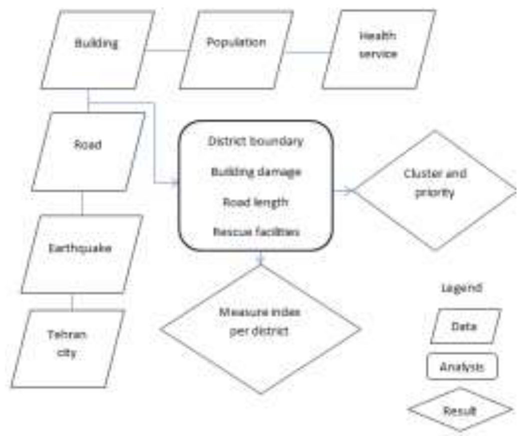

Figure 7. Proposed framework for leveling the districts

4.1 Data Analysis

To determine the relationship between the demand and selected parameters a linear regression analysis was performed. This analysis was based on Stepwise Regression. Selected parameters included population (p), area(s), main roads length (L1), secondary roads length (L2) and A (mentioned above). The results showed the highly correlated between D (expected injured people) and p as expected. There are also a large number of rescue centers in the areas included with fewer injured people. So there is an incompatible distribution between facilities and demands. The other results of analysis showed enough correlation between road lengths and D. But the district with the more injured people and the more length of secondary roads the more difficult will be the disaster management and relief operations. Instead the districts with the more injured people and the more length of main roads reduce districts vulnerability. Detailed analysis is represented in appendix1

4.2 District Classification

There are different ways to cluster districts. Using statistical methods, such as standard error of the mean causes further groups. In this study, according to the graded in three categories, as in the status bar graph shows(fig 8), accessibility index at three levels include (poor) to less than 5, (the moderate) (for values between 5 and 15) and (appropriate)for amounts above 15 was classified

Table 5. Accessibility levels and parameters of the districts in tehran traffic central restricted zone

dist. No	Pop. (pers),p	population density (pers/hect),s	Main roads length (m),L1	Sec roads length (m),L2	Main roads density (m/hect) ,B	Main to sec. roads ratio ,C	No of relief centers ,A	Daytime demand ,D	Accessibility index, AI
1	10560	341.3	1284	9390	2	11	17	26	1.1
2	15448	330.9	4178	11841	5	27	22	38	1.4
3	25919	458.4	3310	16367	3	16	17	64	0.6
4	11621	281.4	4736	9731	7	37	17	29	2.1
5	29527	340.2	6758	22931	8	23	22	73	0.7
6	28718	290.3	3859	22214	6	13	26	71	0.6
7	13481	117.3	5786	16177	21	28	43	34	2.7
8	17472	187.8	8344	16703	19	38	74	43	3
9	8603	122.9	9986	9508	34	81	57	21	8
10	22601	256.6	8088	18052	13	34	26	63	1.2
11	23335	133.9	9132	36331	29	19	26	65	1.1
12	31651	301.9	9825	23117	14	33	26	89	0.8
13	14369	90.4	5724	11855	26	37	26	40	2.2
14	7127	44.6	7574	40174	71	15	43	20	6.5
15	27299	225	7033	36215	13	15	43	76	0.9
16	23046	341.2	9916	16575	12	46	22	64	1.2
17	14497	186.9	5383	14897	12	28	26	41	1.6
18	5125	113.4	7570	22257	28	26	22	14	5.3
19	23619	109.5	8327	24913	32	26	35	66	1.4
20	35758	237.9	12693	23428	22	42	30	100	0.9
21	17802	146.8	17866	21316	51	64	39	50	3.1
22	12986	116.3	25664	19765	92	100	74	36	7.3
23	17472	137	8038	18402	25	34	57	14	8.4
24	9499	62.7	14994	14492	100	80	100	7	37.9
25	11741	114.2	9157	12058	34	58	78	9	18.7
26	12806	89	15366	19945	72	59	100	10	23.3
27	12747	161.8	13091	12770	34	79	70	10	18.4
28	10527	119.3	11782	16002	41	57	52	8	18.4
29	20359	212.5	8788	17831	17	38	26	25	3.2
30	10964	159.5	5476	7080	14	59	30	14	7.7
31	24208	313.5	6043	17027	8	27	43	30	2.6
32	14100	374.2	6506	10147	7	49	65	18	6.9

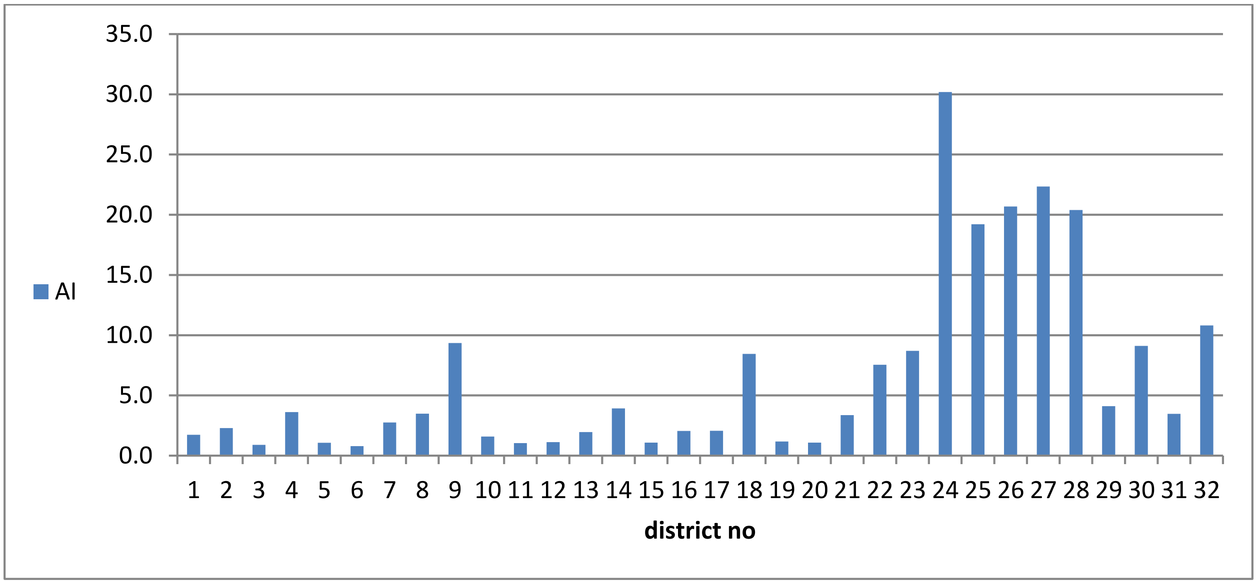

Figure 8. Accessibility index (AI) in district

5. Conclusions, Suggestions, and Future Research Horizons

Considering the problems and the importance of the accessibility of the central parts of Tehran after a probable earthquake, the facilities and accessibility levels were studied for relief operations. To evaluate the performance possibility, the area under Tehran traffic plan was investigated at the scale of the districts situated in it. Accordingly, the ratio of the facilities to the requirements (supply to demand) was evaluated separately for each district through a very simple relation proposed in this research. Facilities (supply) include number of centers (hospitals, emergency departments, firefighting stations, disaster management centers, etc.) involved in relief operations, density of the main roads length, and ratio of the main to secondary roads, and requirements (demand) is the number of the injured requiring relief. Main roads were considered as one separate parameter because of the role they play in post-earthquake conditions, and the ratio of the main to secondary roads was taken as another because the latter have high closure probability and impermeability to the affected areas for rescue and relief operations. To determine the main demand parameter, the difference between the number of fatalities in two states (with no relief, and with public relief + professional help) taken from JICA for Tehran was used. Since the Japanese group had released the results of its studies for different districts of Tehran, we evaluated the parameters of each district considering its population and location in Tehran. Next, these parameters were co equalized with their corresponding maximum values and scaled in the 0-100 range. The final results are shown in Table 5 as the accessibility indices separately for each neighborhood (totally 32 in Tehran traffic central restricted zone). Accordingly, neighborhoods 1, 2, 3, 5, 6, 10, 11, 12, 15, 16, 17, 19, and 20 have poor accessibility (with indices less than 2), neighborhoods 24, 25, 26, 27, and 28 have acceptable accessibility (with indices more than 15), and other neighborhoods have medium accessibility (with indices 2 - 8.5). As shown, neighborhoods with limited accessibility (in the southern part of the central restricted zone) are located mostly in areas with worn out tissues or with high populations and are, therefore, more susceptible because of their closeness to Rey fault. Neighborhoods with better medical facilities, fewer low-width roads, less population, and far from Rey fault are located in the northern part and have better accessibility. At the end a point to be considered in planning for disaster management is to pay attention to the management insight that can be solved in times of emergency which many important decisions depend on this factor. Insights gained through experience and difficult decision making are how one becomes a manager in the struggle against disasters.

8. References

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Appendix: Stepwise Regression: D versus P; S; K; L1; L2; B; C; A

Alpha-to-Enter: 0.15 Alpha-to-Removes: 0.15

Response is D-N on 8 predictors, with N = 32

Step	1	2	3	4
Constant	-13.3333	1.8059	0.1203	-3.9984
P	0.00300	0.00272	0.00263	0.00249
T-Value	10.75	9.92	9.93	9.06
P-Value	0.000	0.000	0.000	0.000
A-N		-0.241	-0.371	-0.356
T-Value		-2.69	-3.47	-3.41
P-Value		0.012	0.002	0.002
L1			0.00100	0.00083
T-Value			2.02	1.69
P-Value			0.054	0.102
L2				0.00041
T-Value				1.58
P-Value				0.126
S	12.1	11.0	10.5	10.2
R-Sq	79.39	83.50	85.59	86.81
R-Sq(adj)	78.71	82.37	84.05	84.86
Mallows Cp	8.8	3.4	1.7	1.5