

The methodology for reconstruction significance of transportation network links under the flood damage

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Abstract: The significance of the transportation network links in the reconstruction period of flood crisis occurrence depends on variety characteristics. One of these characteristics is the accessibility index in the road transportation network. Each of the network links plays a different role in creating the accessibility inside and outside the road transportation network. The more paramount this role is, the more significance that link would be in the network. In the present investigation, reconstruction significance of different link of the Golestan province road network has been determined based on the accessibility index and probability of flood damage. In this paper, for estimation of probability of flood damage, the flood peak was determined based on the maximum daily discharge. In order to assess the flood peak for different return period's frequency analysis (HYFA) software was used. Finally, the probability of flood damage as a result of destruction of the bridges due to flood was determined. For estimation accessibility index, the roads network was modeled by EMME2 software and then, the network was loaded based on daily traffic volumes. The accessibility index based on the traffic volume was determined and assessed before and after flood. The probability of flood damage is utilized as a coefficient for the accessibility index in the paper. According to the obtained values, the degrees of significance of the different network links were prioritized in the occurrence of flood. The reconstruction significance of different links of road network has been determined based on probability of flood damage multiplied by accessibility index. Generally, it can be concluded that merely using the accessibility index does not suffice in reconstruction significance the transportation network links against flood. Consequently, another index needs to be assessed simultaneously with the accessibility index. This index is in fact the probability of the destruction of the bridge due to flood. In the composed index, a merged form of these two proposals has been presented. [Khaki A.M, Shariat Mohaymany A, Sadati Baladehi S.H, Elyasi Gorji A. **The methodology for reconstruction significance of transportation network links under the flood damage.** *Life Sci J* 2013;10(6s):211-221] (ISSN:1097-8135). <http://www.lifesciencesite.com>. 33

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1-introduction

There seems to be a consensus that natural hazards or disasters have a huge impact on human society in many respects. While different types of natural hazards are associated with different time spans of impact and varying levels of damages, the consequence of a disaster is devastating in many cases. A number of studies rooted in physical environment have focused on understanding the mechanism of the disaster and the immediate physical damage. However, there have been only a small number of works devoted to exploring the potential impact of the disaster on society, and, the retrofit and restoration strategy against the disaster, even if the number has increased in the 1990s among disciplines such as geography, regional science, urban planning, and transportation studies. One major reason for the lack of studies in related to the difficulty of interdisciplinary approaches. For example, to assess an economic impact of a disaster, a researcher has to derive a way to convert the physical damage from the disaster into some other

measure showing the damage on society. This is not a trivial task. Various assessment frameworks have to be developed related to different types of natural disasters as well as different types of impacts to be assessed in order to derive a proper methodology to convert the physical damage into the social damage. Flood may not be a natural disaster that imposes as spectacular damages as earthquakes or hurricanes do. However, flood is likely to occur more often than many other types of disasters since even man-made disasters (e.g. collapse of a dam) as well as different types of precipitation (heavy rain, snow, and hurricane) might be a potential trigger of the flood. In this respect, it is hard to determine which type of disaster is more harmful than others in a general context. While is not a lot of actions can be taken to get rid of natural disasters themselves, there are some ways to relieve the damage from disasters, such as pre- disaster measures (retrofit) and post-disaster measures (restoration). If those measures are efficiently implemented, the damage can be greatly reduced. Such efficiency is often related to budget

constraints on retrofit and restoration. For example, when the transportation network has to be retrofitted, all the links with the risk of potential disruption can be retrofitted at the same time if there is no budget constraint. If there is a budget constraint, however, not every link can be retrofitted all at once. Rather, a certain type of priority has to be established among those links in the retrofit process in order for the result of the retrofit to be effective.

2. Literature review

While it is not difficult to find a research devoted to flood in general, the number of research is relatively small if focus is on something more than the physical characteristic of flood and on corresponding implications in regional planning. This type of study is usually interdisciplinary since the study needs to consider approaches from physical and social sciences. The review here is limited only to those interdisciplinary literatures.

One of the concerns related to flood from a planning perspective in the size of damage it causes. Different studies have measured the level of damage with different methodologies. Using a china example, Renyi and Nan (2002) calculated flood area with GIS techniques. Flood e damage in their study was estimated using the overlay operation of different land use patterns. The damage was measured as the ratio of flood area to the total area by each land use. They concluded that while their method was succinct and inexpensive, the result showed a satisfactory performance.

Lekuthai and Vongvisessomjai (2006) focused more on assessing the economic damage of flood. They divided the total damage into tangible and intangible ones. The tangible damage was the direct function of flood depth and duration. To quantify the intangible damage in monetary terms, they used anxiety – productivity and income interrelationship approach. Based on the estimation results from the Bangkok data, they have found that a substantial portion of damage was made from the intangible one.

Nicholas et al. (2003) attempted to establish a conceptual model to work through the flood damage estimation process on the UK properties. According to the authors, it was very difficult to find the single optimal repair strategy due to a large variation in assessment. In their standardized assessment, flood damage was a function of flood characteristics and building characteristics. Damage was measured as the flood damage repair index. Wurbs et al. (2001) introduced uncertainties in the estimation of average annual damage of flood. In the study on college station, TX, they adopted Hydrologic Engineering Center (HEC) simulation models of the US Army Corps of Engineers. They suggested that stochastic approach is more reasonable for implementing risk –

based analyses since these types of analyses are associated with various aspects of uncertainty.

From the regional planning perspective, it is important to have a well-established decision support system when choosing the most appropriate mitigation strategy against flood damage. It is especially so, if the policy decision maker is not an expert in assessing the impact of this type of natural disasters on the region. Ahmad and Simonovic (2004) attempted to build a system to support the decision of appropriate flood damage reduction measures. The intelligent flood management system in their study, which is based on the HEC models, is an integration of heuristic knowledge and analysis tools. The approach of Wurbs (1996) is to optimize a flood damage reduction measure. The decision in his approach has to be made on the size of each structural component. The optimized policy alternative is obtained when the total system cost is minimized. The total system cost is the sum of the discounted annual cost of implementing and maintaining each measure, and, the residual of expected annual flood damages. A series of papers of Correia et al. (1999a, b), focusing on the Portuguese example, examined the relationship between floodplain management and urban growth. They have linked urban growth scenarios with the corresponding flood conditions using GIS overlay functions. In the conclusion, the papers suggested an integrated system of GIS on floodplain management. In a similar context, Correia et al. (1998) proposed an integrated decision support system that embraces GIS, and, hydrologic and hydraulic flood modeling.

Rather than establishing the optimal type of policy measures, Loë and Wojtanowski (2001) have evaluated the current flood reduction program in Ontario, Canada. They focused more on associated benefits and costs rather than the primary ones of the project. Using a Delphi approach, the study identified the benefit and cost related to environmental protection, land use planning, floodplain management, and others. While the cost was not considered important by the expect group, examples of the suggested benefit included an improved administration of zoning in hazard areas and the protection of important environmental features. Hence, the result of the study supported the existence of the flood damage reduction program in Canada. McAllister et al. (2000) have taken the priority of policy measures into consideration. Limited resources and a constrained budget in many cases do not allow all the potential problems to be solved all at once. They policy decision maker, therefore, needs to be more selective in reviewing the necessity of retrofit and repair of a certain facility and to establish a priority list of budget spending among the

alternative measure. McAllister et al. (2000) attempted to prioritize wetland restoration to optimize flood attenuation at regional scale. The decision criterion in the study was the marginal decrease in total downstream flood volume per restoration dollar. They calculated the priority index, ranked sub-units of the region, and mapped those to show the spatial distribution of the priority index over the region.

Similar to the analysis in this paper, løvås (1998) established an order of significance of links. He modeled escape ways of the building evacuation system as a network with links and nodes. The analysis is performed to identify the importance of different network components. According to the author, a link or a node is important if its removal has great implications on the system's performance. Different criteria are used to examine the importance including structural importance of link cuts, structural importance of links, performance – based importance of links, and time dependence of importance. Many of them are the applications of measures used in the graph theory. Even if it not about network system, the study of Davidson and Lambert (2001) shares the similarity with løvås's (1998) in twofold. First, their study tried to quantify the potential risk of each county. Second, it attempted to set an order by the magnitude of risk. They developed hurricane disaster risk index to quantify the relative risk of economic and life loss in 15 different coastal counties in the US. Factors considered in calculating the index include hazard-related, exposure-related, vulnerability –related, and emergency response and

recovery capability. Different weights are assigned to different factors based on the finding from the analytical hierarchy process. According to the authors, the index is expected to help resource allocation decision among counties.

3- Methodology

According to the above – mentioned ideas, the research method is divided different stages.

- modeling the road network of Golestan province,
- loading the road network of the province,
- determining the accessibility index for the existing condition,
- determining the accessibility index for different scenarios (after occurrence the flood),
- determining the different of accessibility before and after link – loss for each of the links,
- extracting the statistics related to the daily and instantaneous maximum discharge, of the rivers in the region in the annual statistical year,
- assessing and analyzing the instantaneous maximum discharge or flood peak based on different return periods,
- determining the capacity of water passing from the bridge sections,
- determining the probability of flood damage in the links under study,
- merging the probability of flood damage with the accessibility index,
- reconstruction significance of the transportation network links based on the new merged index.

The methodology of the present research could be process into the following:

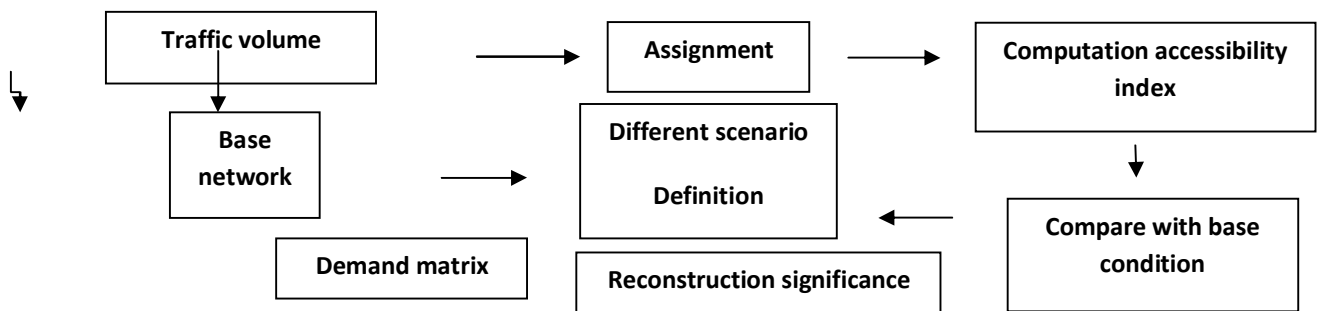


Fig .1: Process reconstruction significance of road network links based on the accessibility index.

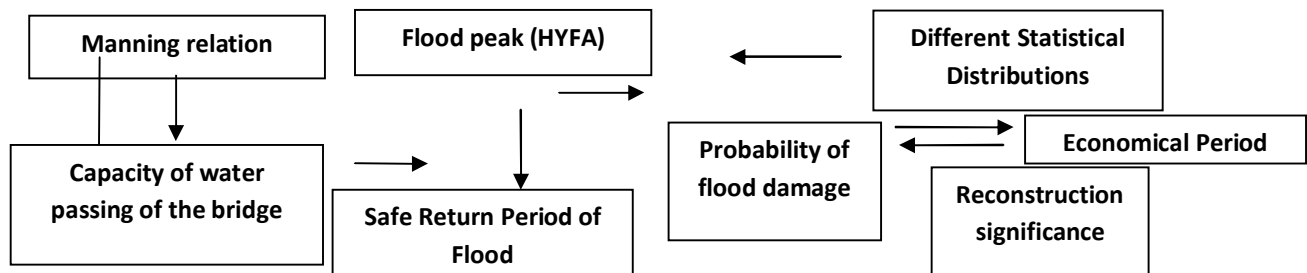


Fig. 2: Process reconstruction significance of road network links based on the probability of flood damage.

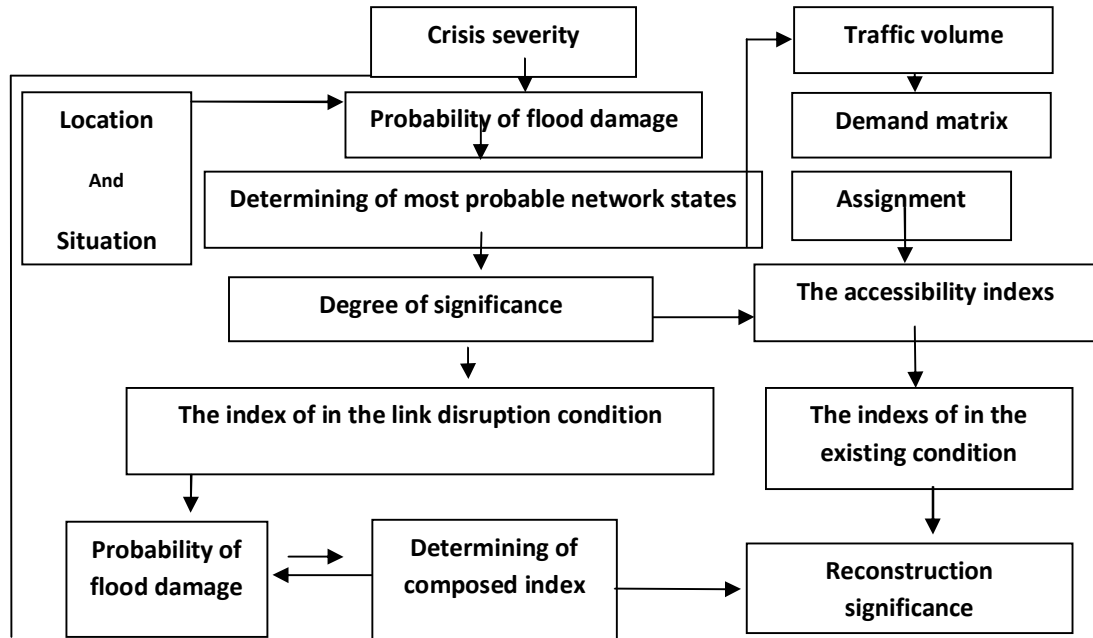


Fig. 3: process the reconstruction significance of the transportation network links based on composed index.

4- Determining of the accessibility index

Accessibility is an indicator which is used to depict the easiness of the relation between two or more points or even between a point with more than one points and reverse. The accessibility index of the present study could be stages in to the following:

4-1-Determining the accessibility index based on traffic volume and distance

There are two effective parameter in determining the accessibility index. The first is the distance between zones which has a reverse relationship. The second parameter is the traffic volume which has a direct relationship with the accessibility index. Various investigations have been conducted considering the two parameters both singly and together, to determine the accessibility index.

Jungyul Sohn (2006) proposed an index in which both parameters were simultaneously considered:

$$A_i = 4 * \left[\alpha \frac{P_i}{\sum_{K=1}^{24} P_K} \sum_{j=1}^{23} \left(\frac{P_j}{\sum_{K=1}^{24} P_K} \frac{d_{ij}^{-\beta}}{\sum_{K=1}^{24} d_{ik}^{-\beta}} \right) + (1 - \alpha) \frac{P_i}{\sum_{K=1}^{24} P_K} \sum_{j=1}^{23} \left(\frac{P_j}{\sum_{k=1}^{24} P_K} \frac{t_{ij}}{\sum_{K=1}^{24} t_{ik}^*} \right) \right] \quad (1)$$

In which

A_i : Accessibility of zone i

α : Weighted coefficient) $0 < \alpha < 1$)

P_i : The population of zone 1

β : 0.446632 (experimental coefficient)

d_{ij} : The shortest path between *i* and *j* zones in different scenarios

d_{ij}^* : The shortest path between *i* and *j* zones in the existing conditions

$$t_{ij} = \frac{\sum_{m=1}^n AADT_m \cdot d_m}{d_{ij}}$$

The average traffic volume between *i* and *j* zones

$AADT_m$: The average annual daily traffic in link *m*

d_m : The length of link *m*

In the first part of the above-mentioned relationship, the distance parameter has been considered in determining the accessibility indicator. In the second part, traffic volume indicator determines the accessibility index between origin and destination. The α coefficient in this relationship is the coefficient whose change, could change the percentage of effects of the two-mentioned parameters in determining the accessibility could be either increased or decreased. For example, $\alpha=1$ means that only distance has been utilized in

determining the accessibility index $\alpha=0$ demonstrates that the accessibility index is determined solely based on the parameter of traffic volume. If we suppose that only Accessibility index has influence on

reconstruction significance of the transportation network links, then the results have been illustrated in figure 4.

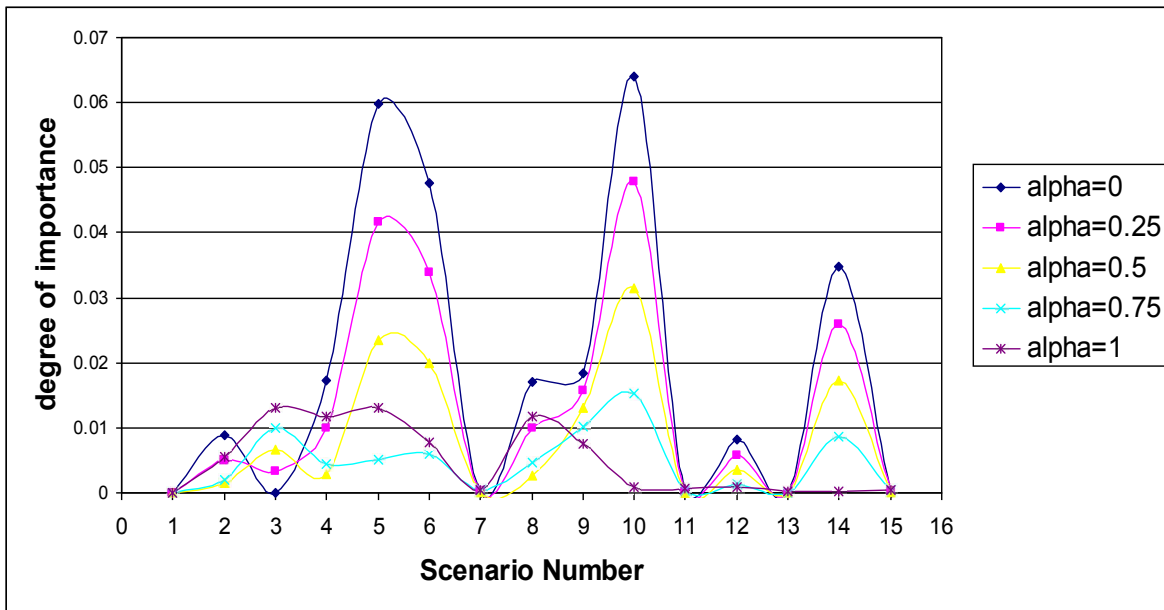


Figure 4: Results of reconstruction significance of transportation Network links based on Accessibility index (traffic volume)

According to the result of figure 4 the α coefficient nears 1 (The condition in which only distance is the influential factor in assessing and determining the accessibility index), the amount of changes in the accessibility in relation to the existing condition will decrease. This is owing to the little sensitivity of accessibility index in defined mathematical relationship to the distance parameter.

In conditions in which the traffic volume parameter play a role in determining the accessibility index (i.e. $\alpha=0$, $\alpha=0.25$, $\alpha=0.5$, $\alpha=0.75$, $\alpha=1$) those links in the network have great level of importance whose disruption will lead to considerable increase in traffic volume in the substitute links for example links number 3, 8 and 14.

in condition in which distance parameter is the only influential factor in determining the accessibility index $\alpha=1$, those links in the road network enjoy greater significance which are the only accessibility links in their zones and their disruption will cause that the substitute links in other zones and with longer distance transfer the traffic volume . For example link 3, 5 and 8.

4-2-Modeling the Road Network of Golestan Province

In order to calculate the accessibility index of different zones, it is necessary to model the road network of Golestan Province (case study) along with

the trip production and attraction zones in this province. To do this EMME2 Software was selected. EMME2 is software which has been increasingly utilized in transportation planning. There are three types of databases in the understudy area, Golestan Province Road Network.

1. Network (province road network)
2. Matrix (origin-destination matrix)
3. Functions (the mathematical formula of accessibility index)

The modeled road network of Golestan province has been illustrated in figure 5.

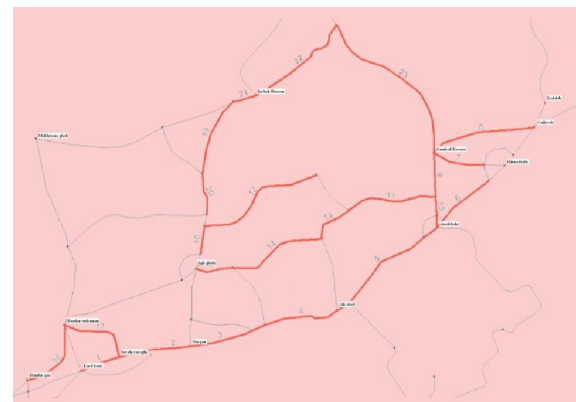


Figure 5: The Modeled Road Network of Golestan Province

Having modeled the road network of Golestan Province in the Software of EMME2, the origin-destination matrix of daily trips throughout the province was assigned to the network. The loaded network in the existing situation has been illustrated in figure 6.

4-3-Assessment of the Accessibility index in the Existing Conditions

In this stage, the manner of calculation of accessibility index, presented in the previous section, was determined by QBasic Programming Language. Then, using the programming language of Macro net, the existing characteristics in the province road network system, trip production and attraction zones were determined as the input of the program of QBasic and the accessibility index in the existing condition was calculated.

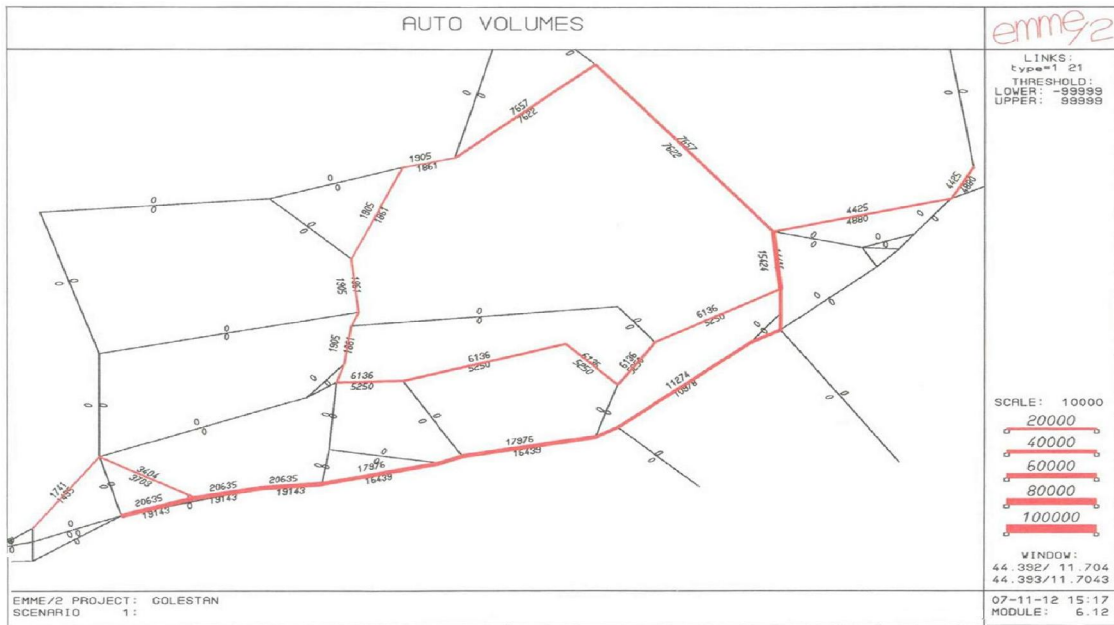


Figure 6: The Loaded Network of Golestan Province in the Existing Condition

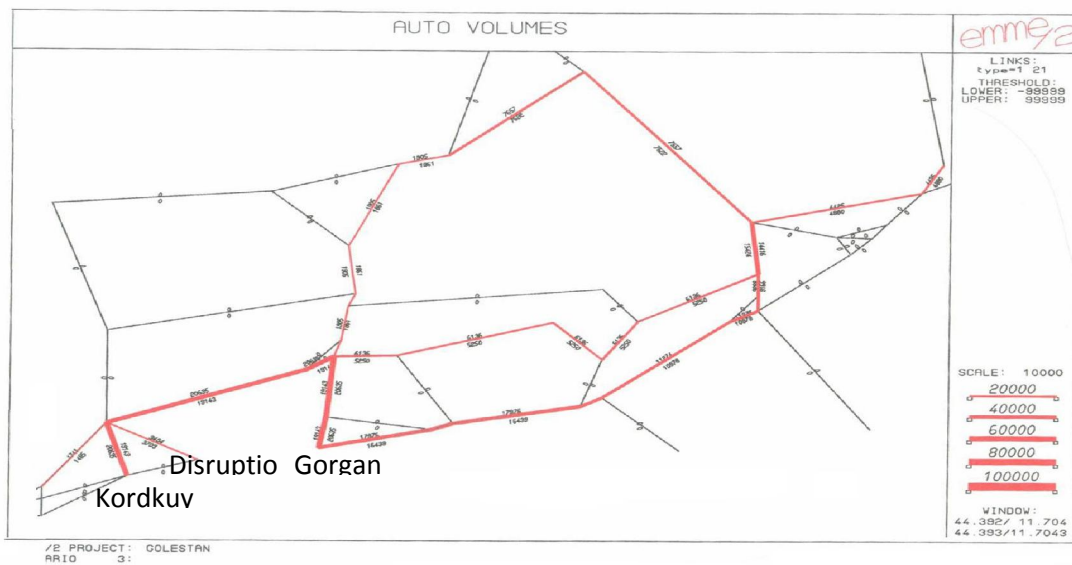


Figure 7: The Loaded Road Network of Golestan Province in the condition of link-loss between

4-4-Assessment of the Accessibility index in different Link-disruption conditions in the network

In this section, assuming the flood occurrence in the road network of the province, and loss of each of the existing links of in the network, scenarios were defined and developed. After that the origin-destination matrix was assigned to the new network,

after the link-loss for each of the scenarios, the amount of the new accessibility index for all production and attraction zones was assessed. In figures and 7, 8 the loading of the province road network in the link-loss condition between (korkuy – gorgan) and (gorgan – Aliabad) has been illustrated. Correia and saraiva (1999a), Kim and boyee (2002)

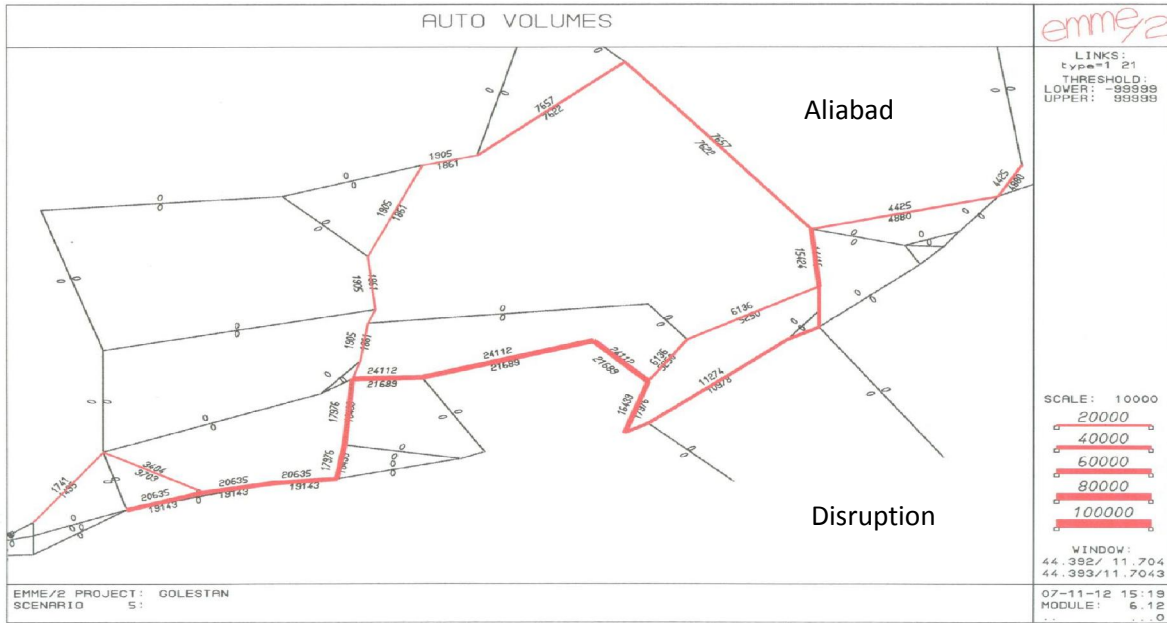


Figure 8: The Loaded Road Network of Golestan Province in the condition of link-loss between Gorgan

5- Determining of the probability of flood damage

For estimating probability of flood damage of the present study could be stages into the following:

5-1-the assessment of flood peak

According to find a flood peak for every station, given the fact that some of stations in a year or years do not have a certain statistics. In order to complete the lack of current statistics, we planned to setup relation for stations having lack of statistics as shown in the table (1) and it is being presented. The next step was the flood peak calibrating and after those distributions of probability in different return periods by the usage the hydrologic frequency analysis (HYFA) software was estimated. Ahmad and simonovic (2001) the mathematical relation between the flood peak and maximum daily discharge could be defined as follows:

$$Q_p = a + b Q_D \quad \& \quad Q_p = a Q_D^b, \quad n, \quad r \quad (2)$$

In which:

Q_p : the flood peak in the station/ m^3 per second

Q_D : the maximum daily discharge in the station/ m^3 per second

- N: the number of years which have the statistics related to the instantaneous and daily maximum discharge
- R: correlation coefficient
- a and b: calibration coefficient of the model.

In order to assess the maximum instantaneous discharge for different return periods, the hydrologic frequency analysis (HYFA) software was used. In this method , different statistical distributions such as log normal with 2 and 3 parameters , gambel , pearson, log pearson type 3 , gama with 2 parameters and etc. have been regressioned to the completed statistics of maximum instantaneous and daily discharge in the hydrometric stations. According to the values of x^2 test and the least square method, the best normal distribution have been selected and using them, the maximum instantaneous discharge has been assessed in the selected hydrometric stations for different return periods. The process of calibrating the correlational relationships for some of the hydrometric stations has been illustrated in the figure 9 to 10.

Table (1): The correlation of completion of the flood peak in elected stations

No.	Name of station	Correlation coefficient	n	r
1	Gonbad	$QP=1.2791QD-2.9053$	35	0.99
2	Pas Poshteh	$QP=1.8349QD+2.4853$	33	0.93
3	Araz Kooseh	$QP=1.0006QD+35.771$	35	0.91
4	Ramian	$QP=2.2863QD^{0.9466}$	34	0.80
5	Nahar KHoran	$QP=1.0459QD^{1.3216}$	28	0.94
6	Agha Ghala	$QP=0.9858QD+8.5428$	36	0.99
7	Siyah Ab	$QP=1.0461QD+3.7387$	29	0.89
8	Niyaz Abad	$QP=1.0097QD^{1.0097}$	10	0.99

In the Table (1) the values of the flood peak assessed in the selected hydrometric station have been shown for different return periods

If in the life time considered for technical structures, the flood amount exceeds the equivalent amount for the hypothesized return period, the structure is destroyed or at least is damage.

5-2- The assessment of the probability of flood damage of links of the road network

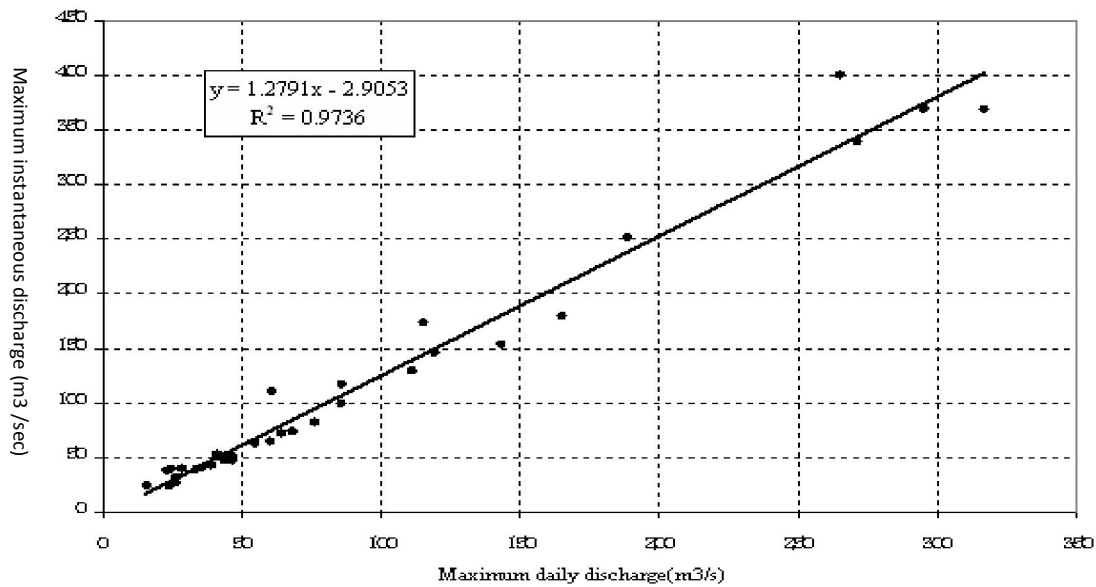


Figure 9: the correlation of the maximum instantaneous discharge in hydrometric station Gonbad

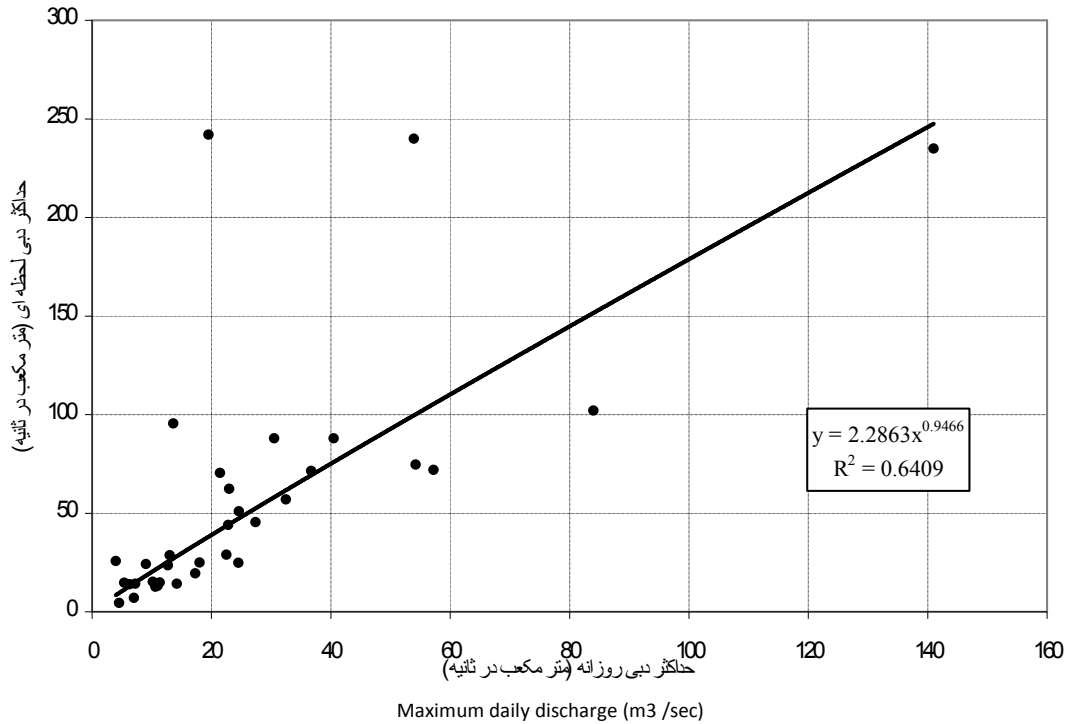


Figure 10: The correlation of the maximum instantaneous discharge in hydrometric station ramian

If we consider p as the probability of the occurrence of an incident, the value of q will be the probability that the incident would not happen:

$$q = 1 - p \tag{3}$$

The probability of flood not to happen in n year or the reliability of that would:

$$R = (1 - p)^n \tag{4}$$

Considering the definition of the return period of flood T , we can present the reliability as follows:

$$Pr = (1 - 1/T)^n \tag{5}$$

Therefore, the probability of flood damage would be:

$$P^j = 1 - (1 - 1/T)^n \tag{6}$$

Table 3: The assessment of probability of flood damage of the bridges

No	Number of link	river	Average length of bridge (m)	Average height from riverbed (m)	Width of bridge (m)	Name of station	Safe return period (year)	probability (%)
1	2	Anjir ab	25	3.20	11	Anjir ab	500	8
2	3	Gharn abad	9	3.40	11	emamzadeh	500	8
3	5	Zarin gol	47.5	4	11	Zarin gol	500	8
4	9	oghan	18	7	8	galikesh	500	8
5	8	Gharah soo	64	12.8	11	Araz koose	500	8
6	14	Goorgan rood	17.5	7.40	8	Agh ghala	200	18
7	17	Gharah soo	22	3.10	8	Siyah ab	200	18
8	18	Gharah soo	32.5	4.50	8	Niyaz abad	500	8
9	19	kafshgiri	10	3.30	11	yasaghi	500	8
10	23	Goorgan rood	39	7.5	9	gonbad	200	18

Considering what was mentioned before and regarding the previously mentioned equation vulnerability value for each of the under-study bridges have been presented in table 3 based on the number of the related links.

6- Determining of the composed index of in this study and reconstruction significance of the transportation network links

We can define the destruction effect of each link the amount of accessibility index of network and based on this, we should calculate the accessibility index in the network two different ways; one state is

when the link of in the current situation. (In the existing condition) The other state is when the link is damaged and the differenced as the effect of destruction on each bridge. (In the link – disruption condition)

These relations can be shown as follows:

$$A^i = \sum_{i=1}^{24} A_i - \sum_{i=1}^{24} A_i^j = \sum_{i=1}^{24} (A_i - A_i^j) \quad (7)$$

A^j : Symptoms due to the destruction of the link or level of destruction effect on link

A_i : Accessibility of area i before the loss of link j

A_i^j : Accessibility of area i after the loss of link j

Table 4: The assessment of final composed index for different links of the road network based on traffic volume and distance

No	Number of link	Accessibility index (traffic volume and distance) ($\alpha = 0.5$)	Probability (%)	composed index	reconstruction significance
1	2	6.58	8	52.64	5
2	3	2.83	8	22.64	6
3	5	19.9	8	159.2	3
4	8	0.23	8	1.84	9
5	9	2.66	8	21.28	7
6	14	0.07	18	1.26	10
7	17	3.61	18	64.98	4
8	18	0.23	8	1.84	8
9	19	23.4	18	187.2	2
10	23	17.3	18	311.4	1

At this stage, the composed index of the bridge destruction is utilized as a coefficient for the accessibility index presented in this study or the composed index defined and determined based on probability multiplied by accessibility index and the risk index is presented for reconstruction significance of the road transportation network links based on the following equation.

$$R = P^j * \sum_{i=1}^{24} (A_i - A_i^j) \quad (8)$$

Which in it:

P^j : Probability of flood damage on link j in T-years period.

R: composed index

According to this the level of composed index for different links of the transportation network are estimated in the Tables (4).

7- Result and discussion

1-in condition in which distance parameter is the only influential factor in determining the accessibility index $\alpha=1$, those links in the road network enjoy greater significance which are the only accessibility links in their zones and their disruption will cause that the substitute links in other zones and with longer distance transfer the traffic volume. For example link 3, 18, 5 and 8.

2- in conditions in which the traffic volume parameter play a role in determining the accessibility index (i.e. $\alpha=0, \alpha=0.25, \alpha=0.5, \alpha=0.75, \alpha=1$) those links in the network have great level of importance whose disruption will lead to considerable increase in traffic volume in the substitute links for example links number 3, 8 and 14.

3- The results of reconstruction significance in case $\alpha=0.5$ (i.e. the effects of two parameter of distance and traffic volume in determining the accessibility index are equal) is presented. In graph no. 1, these are illustrated for different volume of α .

4- in the final the degrees of significance of Golestan province road networks, it can be observed that the link no. 23 which has been considered the 3rd priority based on accessibility index, in the present study has been considered the 1st factor due to its high probability of flood damage. Also, the link no. 8 has been placed in a higher priority compared to link 23, this happened in the opposite order based on accessibility index.

5- Amount of the flood peak of rivers in under study region is indicative of the high precision of the calibrated correlations in different hydrometric station.

6- The result of the assessment of capacity of water passing in the existing rivers shows the high validity of manning relation.

7- The connections and links whose probability of flood damage in times of disaster are more tolerant than the rest of the links.

8- The result of the assessment of probability of flood damage of links (bridge) shows the effect rule and safe return period of flood.

9- According to supervision of some of the bridges which were built based on manning coefficient ($n=0.03$) were observed.

9- Conclusion

The usage of the index suggested in this study for Golestan province shows the use ability of this procedure. Put this project in reconstruction significance for reinforcement the link in network in case of the flood damage.

In this paper to trip assignment, the method of shortest path is utilized; first of all it would be great to study about the method parameters according to the country situation, especially the situation of the trips which have done after the event. Secondly it is necessary to propose a good method to trip assignment after the event in the country.

Achievements or Finding of this paper are reconstruction significance of the transportation network links after the flood damage, based on the accessibility index and combining it by the probability of flood damage.

Generally, it can be concluded that merely using the accessibility index does not suffice in reconstruction significance the road network links against flood. Consequently, another index needs to be assessed simultaneously with the accessibility index. This index is in fact probability of flood damage of the bridge due to flood. In the composed index, a merged form of these two parameters has been presented.

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