Bridges Risk Analysis in View of Repair and Maintenance by Multi Criteria Decision Making Method (Case Study: Babolsar Bridges)

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Abstract

Bridges built from any material and having any special shape will eventually show signs of wearing off; therefore, there are several factors in the kind and rate of such wearing off and its expansion such as atmosphere, flood, earthquake, overload, design quality, execution and kind of materials that will all reduce the functionality of the structures. Thus, maintaining processes and repairing the bridges may increase their life. In this article, after identifying effective risks on the bridges upon using them, critical risks are determined with FMEA method. After distinguishing the critical factors, each one is studied in details. Finally, three bridges in Bablosar (Iran), located over Babolrood River as well as their traffic role between the two sides of the city are investigated. Moreover, their roles on the traffic is also another case of interest in case with the destruction of any of these bridges, the communication to either side of the city faces serious problems. Also, the identified risks for each of these bridges are investigated to discern which of them is in no appropriate condition and if necessary they should be maintained and fortified. To do so, in this research by using AHP, ANP and Topsis Methods, these bridges are prioritized. Results show that the first bridge in this city has a worse state in comparison to the other ones and should be repaired, maintained, or fortified as soon as possible.

Keywords: Bridge, risk analysis, repairing, maintaining, multi-criterion decision making methods.

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1. Introduction

Among highway infrastructures, bridges play an important role in connection and they are one of the major traffic arteries especially in metropolises. It can be easily understood that excessive destruction of a structure or destruction of a bridge, especially the big ones, will have harmful consequences for the management of the metropolis. Moreover, due to traffic problems in metropolises, it will be hard and limited to do repairing operations. On the other hand, initial investment in their construction is very heavy yet if load-tolerance capacity reduces or decreases, the costs for their reconstruction will be higher than that of their construction. Therefore, policy-makers also notice the bridges when most of them have faced problem. Thus their management is the main infrastructure in any country and their timely repairing and maintenance is an important task. Hence providing a supportive plan for decision making for city managers in terms of prioritizing urban bridges for allocation of repairing and maintenance is necessary. Nowadays one of the most important problems of bridge management is those concerning their destruction [Maxwell, 1990]. Mcintyre stated in 1997 that human is the inheritor of bridges which are the result of many years of negligence, insufficient investment and reactionary maintenance [McIntyre, 1997]. Also, Henry Petrosky in 1995 in his book entitled "Engineers of Dreams" wrote that the humans bridges are also under the influence of their surroundings and traffic, pollution, inappropriate use and negligence in their maintenance has caused harmful effects [Petroski, 1995]. As a result, there are factors which directly or indirectly limit the bridges' power and performance. As a result, identifying these limits and persistently supervising them to prevent likely destructions is necessary to avoid the aforementioned problems. Upon forgetting these criterion, a situation is caused in which for five bridges located in the USA, at least one is under structural problems [Rayal, 2006]. In the USA, 125000 bridges have been evaluated as structurally problematic. Results of this research showed that at least 90 billion dollar is needed to tackle this problem [Aktan et al. 1996; Dunker and Rabbat, 1993].

A wide array of research has been conducted so far in the field of bridge repair and maintenance, each of which has addressed a different area in the field [Li and Kim, 2007; Zhiano et al. 2010; Orcesi and Frangopol, 2011a; Orcesi and Frangopol, 2011b; Yin et al. 2011; Stemberg et al. 2013; Gholami et al. 2013; Barone et al. 2014; Hu et al. 2015; Wu et al. 2017; Xie et al. 2018], But, the main problem is caused by transportation offices which is the costs of maintenance and repairing the bridges that need a great allocated budget. Postponing the maintenance and not prioritizing the allocated budget to bridge repairing projects only aggravates the situation. If bridge destruction reaches to an extent which is not suitable to tolerate some vehicles, it is problematic structurally and is not secure anymore. When the bridge is considered inefficient, which is not suitable to serve different kinds of traffic, it can be due to insufficient width or height or to unsuitable extension of the bridge and road [Jones, 2002]. Considering the increase in the costs of bridge repairing and maintenance from a year to the next and for suitable exploitation, their maintenance in a common physical situation needs a strategy to be regularly repaired and maintained so that the main problem faced by repairing and maintenance authorities of the bridges, i.e. executive (available) budget which is usually less than the one required for all bridge repairs is appropriately allocated to the projects. Therefore, due to the limited costs in order to repair and maintain the bridges, it is necessary to prioritize the existing bridges in a city in order to allocate the budget for their management, repair, and maintenance. Based on the importance of the topic, Zhang and Wang conducted a study in 2017 concerning bridge prioritization considering budget constraint conditions [Zhang and Wang, 2017]. One of the most important issues in bridge prioritization is that of the existing risks in regard to bridges. Different studies concerning bridge risk have been conducted so far by taking account the bridge risks in operating mode. For instance, Gschnitzer et al. (2017) and Alfieri et al. (2018) investigated bridge risk in conditions where a flood has occurred, Kameshwar and Padgett (2014) and Wang et al. (2014) in earthquake conditions, and Leander et al. (2018), Kużawa et al. (2018), and Berthellemy (2018) in fatigue conditions. However, none of the conducted studies has simultaneously investigated multiple risks in bridge operating mode.

With regard to the importance of bridge protection and maintenance, it is attempted in this paper to investigate the bridges in Babolsar in north of Iran which is one of the very important and tourist cities of the country in operation mode. Therefore, FMEA Method is used in the present paper to determine the critical risks of the bridges in their operation mode. Eventually each of these risks is analyzed very accurately for Babolsar's bridges and the status of the existing three bridges in this city has been compared to one another. Finally, upon using multi criteria decision making methods of AHP, ANP and Topsis, risk status of each of these bridges is prioritized, the results of which will show which of them should be repaired and maintained so that the bridge can be improved based on the situation to avoid any further problems.

2. Methodology

2.1 Multi Criteria Decision Making Methods

Human mostly faces the issue of decision-making and the choice of an option among some available ones. These decisions are ranged from personal and individual issues to the big ones. In most of these decisions, there are several goals and factors and the decision-maker tries to choose the best and most ideal option between the several available cases (limited or unlimited). In these cases, the decision-maker faces various options under various criteria that affect the internal or external environment of the system. In this case, multi-criteria decision making models are considered as one of the most effective tools for making decisions. These kind of methods have been used in many construction management issues in recent years [Shahabi et al. 2016; Abdollahzadeh et al. 2013; Abdollahzadeh et al. 2014; Shahabi et al. 2014; Nazarpour et al. 2014].

Three methods are in the present study for solving the employed multi-criteria decision-making model. These methods, including AHP, ANP, and TOPSIS, will be detailed below.

2.1.1. AHP Method

This method has been proposed based on the analysis of human brain for complicated and fuzzy problems. This method was first introduced by Thomas L Saaty in 1970, so that numerous applications regarding this method have been argued since then. A huge attention has also been paid to analytic hierarchy process (AHP) among Multi-Criteria Decision Making methods to resolve ranking problems, so that over 1000 scientific sources have mentioned AHP method during the last 15 years [Rieetveld and Ouwesloot, 1992]. Recently, application of AHP has been widely considered as a useful tool in multi-criteria decision making method for localization of a site for limestone quarry expansion and distribution centers [Ozer, 2007; Dey and Ramcharan, 2008].

Handfield et al. (2002) used analytic hierarchy process (AHP) to select supplier. Bhutta and Huq (2002) also used this method for the same purpose. Further, Schenkerman (1994) did not accept the use of reverse ranking in analytic hierarchy process (AHP) in his article. One year later, Luis G.Vargas (1994) proposed an article in response to Schenkerman, in which he gave a response to the objections raised by Schenkerman in addition to granting support to AHP. In the AHP method, a matrix may be consistent or inconsistent. In a consistent matrix, it is easy to calculate weight which is obtained through normalization of every single column. Beside the weight calculation, it is of great importance in an inconsistent matrix to calculate the value of inconsistency. It can be stated in general that the acceptable value of inconsistency of a matrix or system depends on the decision-maker, but Sa'ati presented 0.1 as the acceptable limit and stated the judgments should have been reconsidered if the value of inconsistency had been more than 0.1. If the entries of a matrix gets a bit far from consistency, so will its eigenvalues. Moreover, based on the definition, the following is for every square matrix A:

$$A \times W = \lambda . W \quad (1)$$

where W and λ are the eigenvector and eigenvalue of matrix A, respectively. Where matrix A is consistent, one eigenvalue is equal to n (the greatest eigenvalue), and the rest are zero. Therefore, in these conditions:

$$A \times W = n.W \quad (2)$$

Since λ_{max} is always greater than or equal to n, and it will get a bit far from n if the matrix gets a bit far from consistency, the difference between λ_{max} and n can be good a measure for the inconsistency of the matrix. The λ_{max}- n measure undoubtedly depends on the value of n (matrix length), and it can be defined as follows to eliminate the dependency which is referred to as the inconsistency index (I.I.), as shown in Equation 3.

$$I.I. = \frac{\lambda_{\max} - n}{n - 1} \quad (3)$$

The values of inconsistency index (I.I.) have been calculated for a matrix where the entries have been set totally arbitrarily, referred to as the random matrix inconsistency index (I.I.R.), the values of which for an n-dimensional matrix are as in Table 1.For every matrix, inconsistency index (I.I.) divided by random matrix inconsistency index (I.I.R.) of the same dimension provides a proper measure for inconsistency judgment, which is referred to as inconsistency rate (I.R.). If the value is less than or equal to 0.1, system consistency is acceptable; otherwise, the judgments should be reconsidered.

2.1.2. ANP Method

ANP method is one of the most widely used multi-criteria decision making methods applied in different fields. Based on Saati's definition, ANP is a more general, publicized, and complete model of AHP which allows the analysis of different issues by having mutual relations among the elements. To measure the weight of this kind of issues, he developed a method called supermatrix [Saaty, 1996]. Supermatrix adjusts the impact of elements' weights that are inter-connected by considering a matrix with all included options and elements. One of its advantages is the fact that ANP sorts not only the elements but also a group or cluster of them based on their priority [Saaty, 1999]. ANP is only a mathematical theory, making it possible to systematically investigate study the different types of interactions as well as dependencies. The reason it succeeded was in the way it extracted judgments and used mathematical calculation operations to measure relative scales.

Priorities are a persuasive numerical basis that meaningfully direct primary calculative

operations [Saaty, 2004]. Therefore, ANP strength is based on using relative scales to control all interactions for accurate prediction and selecting an appropriate decision. Step-by-step stages of ANP can be mentioned as below:
Step One: To initially determine the options and indices and make a questionnaire based on them.
Step Two: To have paired comparisons among the indices and make a paired comparison between the choices for each index, carrying out the same calculations for each option among the indices.
Step Three: To normalize the paired comparisons.
Step Four: To get a mathematical average of each row of the matrix to the normalized paired comparisons (called relative weights).
Step Five: To establish relative weights of the matrix, known as the primary or non-weighted supermatrix.
Step Six: Based on Markoff Chain Method, this matrix is strengthened so much that its rows tend to some constant numbers. In this matrix, the choice with the greatest final weight is the best one.
In order to solve the model using ANP method, the Super Decision software is applied.

2.1.3 Topsis Method

The TOPSIS technique is a popular classical multi-criteria decision-making method which was introduced by Bellman and Zadeh (1970). The logic behind TOPSIS involves definitions of ideal and anti-ideal solutions. The ideal solution is one that maximizes the benefit criteria, and minimizes the cost criteria. In brief, the ideal solution includes all the best values for the available criteria, while the anti-ideal solution is a combination of the worst values for the available criteria. The optimum alternative is the one that is closest to the ideal solution and farthest from the anti-ideal solution. Next, the steps in the TOPSIS method are presented.
First step. Conversion of the current decision matrix to an unscaled matrix which is follows:

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^{2}}} \tag{4}$$

Second step: creating a weighted unscaled matrix (V) with the vector W as input to the algorithm as the following:

$$w = \{w_1, w_2, ..., w_n\} \approx \text{(Given by DM)}$$

$$V = N_D . W_{n\times n} = \begin{vmatrix} V_{11}, ..., V_{1j}, ...V_{1n} \\ V_{m1}, ..., V_{mj}, ...V_{mn} \end{vmatrix} \tag{5}$$

such that ND is a matrix where the index scores are unscaled and comparable, and $W_{n\times n}$ is a diagonal matrix, where only the entries on the main diagonal are nonzero.

Third step: A positive ideal (A+) and a negative ideal (A-) are defined for the alternative:

$$A^{+} = \{(\max V_{ij} | j \in J), (\min V_{ij} | j \in J') | i = 1,2,...m\}$$

$$= \{V_1^{+}, V_2^{+}, ...V_j^{+}, ...V_n^{+}\} \tag{6}$$

$$A^{-} = \{(\min_i V_{ij} | j \in J), (\min_i V_{ij} | j \in J') | i = 1,2,...m\}$$

$$= \{V_1^{-}, V_2^{-}, ...V_j^{-}, ...V_n^{-}\} \tag{7}$$

Where Js and J´s respectively concern the benefits and costs.
Fourth step: Calculation of the distance value.
The distance from the ith alternative to the ideal value is obtained as follows using the Euclidean method:
d_{i+}=Distance from the ith alternative to the ideal

$$\left\{\sum_{j=1}^{n}\left(V_{ij}-V_{j}^{+}\right)^{2}\right\}^{0/5} \quad i=1,2,\ldots,m \tag{8}$$

d_{i-}=Distance from the ith alternative to the negative ideal

$$\left\{\sum_{j=1}^{n}\left(V_{ij}-V_{j}^{-}\right)^{2}\right\}^{0/5} \quad i=1,2,\ldots,m \tag{9}$$

Fifth Step: Calculation of the relative closeness of Ai to the negative ideal solution, as defined below:

$$i=1,2,\ldots,m \quad 0\leq cl_{i+}<1$$

$$cl_{i}=\frac{d_{i}}{\left(d_{i+}+d_{i-}\right)}, \tag{10}$$

It is observed that d_{i+}=0 if Ai = A+, based on which cl_{i+}=1, and d_{i-}=0 and cl_{i+}=0 if Ai = A-. Therefore, the closer the Ai alternative to the ideal solution (A+), the closer the value of cl_{i+}=0 to one.

Sixth step: Ranking the available alternatives in the given problem by cl_{i+}=0 in descending order.

2.2 Failure Mode and Effects Analysis

Within the framework of FMEA, the risk analysis begins with considering a part of a system and by sorting a list of failure modes and rearranging them. Also, their effects are evaluated by calculating an index known as the risk priority number. This method has been used for identifying the risks associated with purchasing procedures of a hospital that has resulted in significant improvement in the purchase procedure of this public hospital [Kumru and Kumru, 2013]. This method has also been used in the field of project management [Bahrami et al. 2012; Taheri Amiri et al. 2015] and bridge risk management [Abdollahzadeh et al. 2016]. Moreover, FMEA can be used in the following three stages [Abdelgawad and Fayek, 2010]:

2.2.1 Identifying Failure modes of a System

In this section, the failure modes of a system are considered and their effects on the system are determined.

2.2.2 Calculation of the Risk Priority Number

In the FMEA method, the critical situation degree is determined by calculating the risk priority number which is in the range of 1 to 1000. RPN is the result of multiplying three factors; the severity of the risk (S), occurrence (O) and detection degree (D). The severity of the risk (S) reflects the seriousness of the destructive effects of the considered risk so the effect of the failure modes are determined. Occurrence is the probability of the occurred failure mode and is derived from the reasons that cause the failure. Also, the detection degree (D) is defined as a measure for current control abilities for finding the cause and mechanism of failure. All three factors are evaluated within the range of 1 to 10.

2.2.3 Reduction of Failure Mode

In this section, team members will try to reduce the effects of identified failures based on the calculated RPN.

In addition to advantages such as providing valuable information of fault tree analysis and supporting failure identification procedures, FMEA has some disadvantages that are stated below:

In order to calculate RPN, there is no reason to multiply S, O and D.

Deficiencies on calculation method by using multiplication as well as analysis method of results

For example, the calculated RPNs of two failure modes with severity, occurrence and detection values of (9, 5, 5) and (6, 7, 6) are equal to 225 and 252, respectively. However, this first failure mode should have a higher priority for optimization and corrective actions due to higher severity.

Failure to distinguish between the importance of inputs or severity, occurrence and detection while calculating RPN

Lack of official guidelines for establishing the relationship of the calculated RPN with the required optimization and correction procedures.

2.2.4 Definition of Linguistic Terms for Input Variants

Based on the opinions of the experts in the input variants realm, three linguistic terms of high, medium, and low are considered. In Tables 2, 3 and 4, the definitions about linguistic terms in a bridge-making project are provided. Definitions on linguistic terms for detection input variant are extracted from the reference which is acceptable for bridge construction project [Kumru and Kumru, 2013].

3. Introducing the Case Study

Bridges in the tourist city of Babolsar in Mazandaran Province are over Babolrood River. The reason to investigate these bridges is they play a strategic role in the city and in case of their destruction, the connection between the two parts of the city is cut. Since the city is a tourist one, in case of these bridges' destruction, there will be many problems for the city which shows the importance of this study on these bridges more than ever.

Figure 1. Aerial view of Babolsar's bridges

Table 1. Random matrix inconsistency index

N	1	2	3	4	5	6	7	8	9	10
I.I.R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.45

Table 2. Definition of linguistic terms for probability of occurrence

Probability of occurrence	Linguistic term
Probability of occurrence more than 55%	High
Probability of occurrence between 15% and 55%	Medium
Probability of occurrence between 1% and 15%	Low

Table 3. Definitions of linguistic terms for influence

Influence	Linguistic terms
Unrepairable with destructive damage to the equipment	High
Unrepairable with scarce damage to the equipment	Medium
Repairable system with low function drop	Low

Table 4. Definition of linguistic terms for detection

Detection	Linguistic term
Project team is able to detect a risk response strategy with high chances of identifying risk event as well as controlling its main reasons and result	High
Project team is able to detect a risk response strategy with average chances of identifying risk event as well as controlling its main reasons and result	Medium
Team project is able to detect a risk response strategy with low chances of identifying the risk event as well as controlling its main reasons and result	Low

3.1 Introducing Bridges of the City of Bablosar

The first bridge of Babolsar: this bridge was constructed in the year 1941 by a German company that contains arched bundle structure and the type of its deck is of steel beams and concrete slabs and has a one-way path. The total area of the bridge deck is 900 m², and the length between backpacks are 96 meters and the length of openings are 96 meters. Additionally, the heights of backpacks are 2.5 meters. It is important to note that this bridge does not contain any columns.

The second bridge of Babolsar: this bridge was constructed on July month of the year 2000, that like the first bridge has an arched bundle structure and the type of its deck is of steel beams and concrete slabs and has a two-way path. The total area of the bridge deck is 1200 m², the length of distances between backpacks is 120 meters, length of openings is 102 meters and the height of backpacks is 2.5 meters. It is important to note that this bridge, just like the first one, does not contain any columns.

The third bridge of Babolsar: this bridge was constructed by Mashin Sazi Arak Company (Car Manufacturer Company of Arak) in the year 2010. The structure of this bridge is of the reinforced concrete type and contains two mid-way columns. This bridge was constructed in parallel to the first bridge in order to reduce the traffic load on the older bridge.

4. Risk Evaluation of Babolsar's Bridges in Operation Mode

To evaluate the bridge risk in operation mode, one has to identify the factors of creating bridges' risk. In the following, the task will be carried out.

4.1 Identification of Bridges' Risk in Operation Mode

For identifying dangerous issues and risks that are related to bridges during the operation mode, Delphi method is used and all experts will have to express their views on the presented ideas. This procedure of exchange of ideas amongst all experts continues until the point where a common consensus is reached on which risks must be considered during the operation mode. After summarizing all the results, the associated risk of bridges during the operation mode are achieved via the following method:

1. Inappropriate design of bridges and type of the structure

2. Influence of the used materials in bridge destruction

3. Inappropriate execution of the bridges and unsuitable quality of the construction

4. Influence of atmospheric conditions on bridge destruction

5. Scour in bridges' abutments

6. Influence of heat changes and creation of cracks in the bridges

7. Influence of age on bridge destruction

8. Earthquake

9. Flood

10. Density of incoming loads

After detecting influential factors on bridge destruction in operational mode, it is necessary to identify the most critical risk and upon a more accurate investigate of this parameter, likely damages, caused by this parameter, are prevented. Therefore in order to prioritize the risks, FMEA method is employed in considered bridges. The result obtained from prioritization is reported in Table 5.
According to the results from Table 6, it is obvious that earthquake, bridge ageing and fatigue, density of incoming loads, and flood are to be considered as critical risks in its operational mode with most bridge damages happening under the influence of these impacts. Therefore, due to the identified critical risks, the hierarchical structure related to bridge risk investigate in operational mode is established based on Figure 2.

Table 5. Use FMEA method to calculate the risk rate of each factors

Risk	Probability of occurrence	Damage intensity	Control rate	RPN rate
Inappropriate design of bridges and the type of structure	5	6	3	90
Influence of the used materials in bridge destruction	3	4	4	48
Inappropriate execution of the bridges and inappropriate quality of construction	3	4	4	48

Influence of atmospheric changes on bridge destruction	2	2	7	28
Influence of heat changes and cracks in bridges	2	4	3	24
Influence of age on bridge destruction	8	5	7	280
Earthquake	3	10	10	300
Scour of bridge abutments and occurrence of flood in bridges	5	5	6	150
Density of the incoming loads	7	5	6	210

Table 6. Results from alternative prioritization with FMEA Method

Risk	FRPN rate	Priority
Earthquake	300	First priority
Bridge aging and exhaustion	280	Second priority
Density of the incoming loads	210	Third priority
Flood and bridge scour	150	Third priority
Inappropriate design and kind of structure	90	Fourth priority
Building materials	48	Fifth priority
Inappropriate execution and quality of construction	48	Sixth priority
Aim and atmospheric conditions	28	Sixth priority
Heat	24	Seventh priority

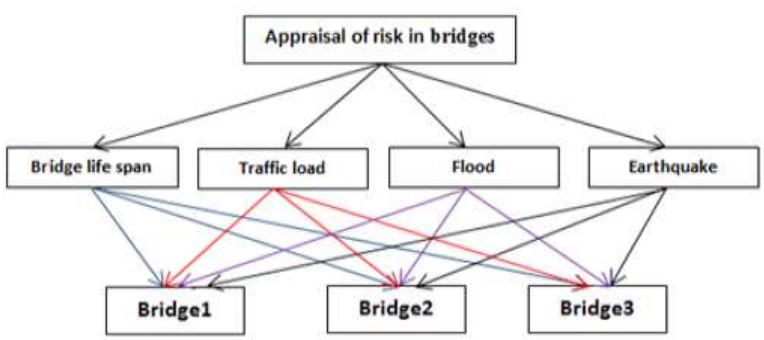

Fig2. Related hierarchical structure of the analysis in bridge's operational mode

4.2 Analysis of Influential Factors on Bridge Risk in Operation Mode

After detecting influential factors on bridge risk in their operational mode, the present paper will accurately analyze the abovementioned parameters on the bridges of Babolsar.

4.2.1 Bridge Ageing

As the bridge ages, the probability of its destruction from exhaustion and erosion grows which is one of the most influential parameters on bridge destruction in operation mode. The age of each bridge in Babolsar is demonstrated in Table 7.

Table 7. The year each bridge of Babolsar was constructed

Bridge	Year of construction
First bridge	1941
Second bridge	2000
Third bridge	2010

According to the Table 8, the first bridge is 77 years old, the second one is almost 18 and the third one is 8. Paired comparison matrix of bridge risk in operation mode is demonstrated in Table 8 by use of experts' ideas.

Table 8. Paired comparison matrix of the choices based on bridge age criterion

	Bridge 1	Bridge 2	Bridge 3
Bridge 1	1	7	9
Bridge 2	$\frac{1}{7}$	1	3
Bridge 3	$\frac{1}{9}$	$\frac{1}{3}$	1

4.2.2 Traffic

One of the most influential parameters on bridge destruction in their operational mode is the flowing traffic through the bridge itself which in long term can have damaging effects on the bridge. Therefore, the passing traffic through the bridge during the rush hour, i.e. 7 to 8 AM, 12 to 1 PM, and 7 to 8 PM, is dealt with the results demonstrated in Table 9, 10, and 11.

After getting the statistics, in order to determine the traffic rate of each bridge and be able to compare them in terms of traffic, it is needed to turn all the vehicles in Table 9, 10, and 11 to a certain vehicle based on predefined coefficients, so that traffic statistics of each of the bridges could be determined during the rush hours in the morning, afternoon, and evening.

Table 9. Traffic statistics, gained from the rush hour in the morning

Bridges	Private car	Taxi	Pickups	Motorcycle	Truck	Bus	Minibus
Bridge 1	1259	192	154	107	7	2	15
Bridge 2	829	34	73	84	10	-	11
Bridge 3	1344	212	98	87	8	2	15

Table 10. Traffic statistics, gained from the rush hour in the afternoon

Bridges	Private car	Taxi	Pickups	Motorcycle	Truck	Bus	Minibus
Bridge 1	1078	171	84	142	8	-	9
Bridge 2	777	20	71	152	10	-	8
Bridge 3	905	165	114	93	16	2	10

Table 11. Traffic statistics, gained from the rush hour in the evening

Bridges	Private car	Taxi	Pickups	Motorcycle	Truck	Bus	Minibus
Bridge 1	1462	134	95	126	4	1	4
Bridge 2	926	32	55	131	8	-	8
Bridge 3	1144	104	64	104	4	-	-

Table 12. Coefficients of different vehicles based on a single private car [Highway Geometric Design Code-No.415, 2013]

Vehicle	Private car	Taxi	Pickups	Motorcycle	Truck	Bus	Minibus
Coefficients	1	1.3	1.3	0.5	4	4	2.5

Table 13. Gained traffic statistics on each of the bridges during the rush hours in the morning, afternoon, and evening

Bridges	Morning rush hour	Afternoon rush hour	Evening rush hour	Sum of the three rush hours
Bridge 1	1835.8	1535	1852.7	5223.5
Bridge 2	1077.6	1031.3	1156.6	3265.5
Bridge 3	1868	1411.2	1430.4	4709.6

Table 14. Paired comparison matrix of the choices, considering the criterion of bridge's passing traffic

	Bridge 1	Bridge 2	Bridge 3
Bridge 1	1	7	3
Bridge 2	$\frac{1}{7}$	1	$\mathbf{\frac{1}{5}}$
Bridge 3	$\frac{1}{3}$	5	1

Thus, all the mentioned vehicles are turned to a single certain vehicle by means of coefficients, represented in Table 12, so that they could be compared in what follows.

The traffic on each of the bridges is obtained based on the private vehicle. This rate for all of the bridges during the rush hours in the morning, afternoon and evening is demonstrated in Table 13.

Therefore based on the results, the paired comparison matrix of bridge risk in their operational mode is obtained based on the criterion of traffic influence on bridge destruction, which is in accord with Table 14.

4.2.3 Earthquake

One of the most influential parameters on bridge destruction in their operation mode is the occurrence of an earthquake which can have very damaging impacts on the bridge. FMEA was used to compare earthquake impact on each of the bridges and comparing them due to this parameter. To do so, the influential factors on the bridges as a result of earthquake were identified which are as follows:

1. Shear failure of the bases
2. Bending failure
3. The fall of the deck from its support
4. Rotation of the packs and bases
5. Penetrating shear of the base in the deck
6. Liquefaction
7. Asymmetry condition of the bases from the central axis
8. Difference between bases' sturdiness
9. Distance of center of gravity from center of sturdiness

10. Difference between adjacent openings
11. Impacts of adjacent foundations on the bridge
12. Local buckling of the elements of steel decks
13. Buckling of steel bases
14. Inflicting strikes between the deck and pack or shear keys

In order to use FMEA in this part the occurrence possibility of each of the above-mentioned parameters should be obtained. Hence, by modeling the bridges in SAP software which assesses bridge seismic analysis, the rate of damage likelihood for each bridge, due to the mentioned parameters, is obtained. In the next step, the intensity of the impact and control rate of each parameter is determined based on the results from questionnaires, completed by experts. Eventually, RPN rate (probability of occurrence* Damage intensity* control rate) of each parameter is calculated, the results of which are given in Table 15 for each one of the bridges.

According to Table 15, in first and second bridges of Babolsar, parameters such as “the fall of the deck from its support”, “rotation of the packs and bases”, “penetrating shear of the base in the deck”, “liquefaction”, “distance of center of gravity from center of sturdiness”, “impacts of adjacent foundations on the bridge”, and “buckling of adjacent bases” are known as critical factors. In the third bridge, parameters such as “shear failure of the bases”, “the fall of the deck from its support”, “penetrating shear of the base in the deck”, “liquefaction”, “distance of center of gravity from center of sturdiness”, “impacts of adjacent foundations on the bridge”, “buckling of steel bases” under the influence of earthquake are known as the critical factors which might get damaged in case of the occurrence of an earthquake in these bridges and it is necessary to take some measures to prevent any problem to these parts. In this section, the criterion for measuring and comparing the bridges to one another is the average RPN, obtained from the different parts.

Table 15. Using FMEA to calculate the risk rate of each part of the bridges

Damage from the earthquake	RPN rate for bridge 1	RPN rate for bridge 2	RPN rate for bridge 3
Shear failure of the bases	27	27	27
Bending failure	48	48	12
The fall of the deck from its support	280	280	280
Rotation of the packs and bases	144	144	64
Penetrating shear of the base in the deck	100	100	100
Liquefaction	160	288	128
Asymmetry of the based compared to the central axis	10	10	10
Difference between bases’ sturdiness	20	20	20
distance of center of gravity from center of sturdiness	108	108	108
Difference between adjacent openings	20	20	20
Impacts of adjacent foundations on the bridge	315	315	140
Local buckling of the elements of steel decks	36	54	24
Buckling of steel bases	400	400	100
Inflicting strikes between the deck and pack or shear keys	36	36	16

Table 16. RPN rates, obtained for each of the bridges

Bridges	Bridge 1	Bridge 2	Bridge 3
Average RPN rate	120.71	132.14	74.92

Table 17. Paired comparison matrix of the choices based on earthquake criterion on the bridges

	Bridge 1	Bridge 2	Bridge 3
Bridge 1	1	$\frac{1}{2}$	5
Bridge 2	2	1	6
Bridge 3	$\frac{1}{5}$	$\frac{1}{6}$	1

Once the average RPN is determined, paired comparison matrix of bridge risks in operation mode can be generated, which based on the earthquake criterion is based on the Table 17.

4.2.4 Floods

Another influential parameter on bridge destruction is the occurrence of flood on the bridges. As a result, hydrological and hydraulic studies on bridges are as follows:

- Hydrological studies to determine the discharge of the design flood (with a return period of 100 years)
- Hydraulic studies to determine and analyze hydraulic impacts of the bridges on Babolrood river.

After conducting the above studies and determining hydraulic parameters such as flow depth, flow speed, Froud number, etc., the free height as well as the depth of scour from narrowing of the flow as well as the local scour depth at the bases and packs are calculated as well.

-Return Period of the Design Flood:

In order to select the return period of the design flood, one must consider issues such as the likelihood of casualties and lethal dangers as well as economic dangers from bridge collapse. Moreover, after having designed a bridge with managing a definite flow rate for a 100-year period, one can not guarantee that a higher flow rate does not occur even in the first year of design, even though the occurrence of such an accident is very rare. Based on the materials from different regulations along with previous experiences of experts, the design for carrying out hydrological and hydraulic studies on the studied bridges is considered to be a flood with a return period of 100 years.

-Determining the discharge of the design:

In order to calculate the maximum discharge, there are many methods such as the logical method, unit hydrograph, S.C.S, calculating the frequency of flood or statistical method, and the district analysis of the flood. Using each of these methods depends on different factors including the objective, importance of the project and existing information and statistics. It is worth noting that in the mentioned studies due to the rather vast basin of Babolrood River along with appropriate statistics at the surrounding water measuring stations, statistical methods are employed to determine the flood discharge of the design. In this project at first the 100-year-old flood discharge of Babolrood is measured based on maximum local discharge statistics at Babol Station, located in Babolrood River, along with Kiakola Station, located in Talar River. The characteristics of the used hydrometric stations are as follows.

-Calculation of flood discharge at hydrometric stations:

In order to determine the maximum flood discharge at the intended stations, for different return periods, at first HYFA Software was used. According to the results from Table 19, it was found that the best frequency distribution in terms of statistical overlap (the distribution that has the minimum standard error) was selected and then based on that, flood discharges were found based on different return periods in Table 20 and 21. As it can be seen in this table, flood discharge with a return period of 100 years was 745 m^3ps and 922 m^3ps for Babol and Kiakola Station, respectively

In this section, based on the results from the above-mentioned studies along with the area of Babolrood river basin at the studied bridges, their flood discharge is measured with discharge-area and Fuller methods. Based on the calculations with discharge-area, the discharge rate is 780 m^3ps and based on Fuller, 808 m^3ps. According to the conducted studies, statistical accuracy and relation of discharge-area for certainty of flood discharge of the design (with a return period of 100 years) is considered to be 800 m^3ps at the studied bridge. After determining the maximum designed flood discharge of Babolrood River in hydrological studies, its hydraulic impacts should be studied in the mentioned river. In order to perform this, hydraulic calculations of the considered river are done with the advanced software program, called HEC-RAC.

Table 18. Features of the hydrometric stations

River	Station	Code	Geographical length	Geographical width	Area
Talar	Kiakola	14-007	52-48-50	36-33-33	2845
Babolrood	Babol	14-017	52-32-49	36-32-43	1430

Table 19. Comparison of different statistical distributions to analyze flood frequency at the studied hydrometric stations

Freq. Distribution	Fitting method	Babol St.		Kiakola St.	
		Mean relat. Dev	Mean sq. rel. dev.	Mean relat. Dev	Mean sq. rel. dev.
NORMAL	Moments	9.9371	293.1313	50.36895	8096.758
	Max. likelihood	9.9371	293.1313	50.36895	8096.758
2LOGNORMAL	Moments	4.85585	53.9977	8.89338	131.2398
	Max. likelihood	4.85585	53.9977	8.89338	131.2398
3LOGNORMAL	Moments	3.38938	21.15915	6.31665	74.57601

	Max. Likelihood	-	-	-	-
2PARGAMMA	Moments	3.14239	17.89916	20.98386	785.2062
	Max. Likelihood	3.34118	22.77694	11.59428	205.1365
PEARSON III	Moments	-	-	-	-
	Max. Likelihood	-	-	-	-
LPEARSON III	Moments Dir.	-	-	-	-
	Moments Ind.	3.51615	23.62618	-	-
	Max. Likelihood	-	-	-	-
GUMBEL EVI	Moments	3.32081	19.88726	31.46435	2637.428
	Max. Likelihood	3.71888	25.64051	10.55677	219.2438

Table 20. Flood estimation with different return periods of Kiakola Station with 3PARLOGNORMAL statistical distribution (in m3ps)

Return Per. Years	Probab. Exc.	Probab. Non.Exc.	Est. Value	St.Error
(T=1/p)	(P)	(1-P)	XT	ST
1.0101	0.99	0.01	41.816	282.71
1.02564	0.975	0.025	49.829	247.354
1.05263	0.95	0.05	58.798	212.003
1.11111	0.9	0.1	72.273	165.32
1.25	0.8	0.2	94.602	100.842
2	0.5	0.5	165.811	47.944
5	0.2	0.8	302.795	161.228
10	0.1	0.9	419.118	169.646
20	0.05	0.95	550.192	138.158
25	0.04	0.96	595.878	134.705
50	0.02	0.98	749.524	233.588
100	0.01	0.99	922.312	485.617

Table 21. Flood estimation with different return periods of Babol Station with 2PARGAMMA statistical distribution (in m3ps)

Return Per. Years	Probab. Exc.	Probab. Non.Exc.	Est. Value	St.Error
(T=1/p)	(P)	(1-P)	XT	ST
1.0101	0.99	0.01	72.898	13.635
1.02564	0.975	0.025	94.976	14.443
1.05263	0.95	0.05	117.187	14.92
1.11111	0.9	0.1	146.819	15.27
1.25	0.8	0.2	188.891	15.609
2	0.5	0.5	290.395	17.978
5	0.2	0.8	422.977	26.937
10	0.1	0.9	506.037	35.171
20	0.05	0.95	582.316	43.854
25	0.04	0.96	605.898	46.705
50	0.02	0.98	676.917	55.673
100	0.01	0.99	745.358	64.774

Table 22. Paired comparison matrix of the choices based on flood and bridge scour

	Bridge 1	Bridge 2	Bridge 3
Bridge 1	1	1	1
Bridge 2	1	1	1
Bridge 3	1	1	1

Accordingly, the computer model of Babolrood river is generated in the designed zone and will then be analyzed. In fact, the aim of such studies is to control the open length and height of the bridges for appropriate flow of the 100-year-old flood through them. Moreover, determining the depth of local scour, next to the bases and packs of the studied bridge is another objective of these studies.

Based on the aforementioned remarks, computer model of Babolrood is generated by means of HEC-RAC and the extracted topography of the river bed is in the studied zone. As a matter of fact, the mentioned models have been generated in accordance with the flow line that connects the deepest parts of the river bed between its perpendicular cross sections. Hence, the points below have been considered in order to generate models and have hydraulic analyses of Babolrood river at the studied bridge:

- Manning coefficient for the main riverbed and the beaches on both sides will be different with regards to ground texture, vegetation, local observations, and previous experiences. This coefficient for the main riverbed is 0.025 and for the beaches on either side is 0.035.

- According to cartographical results as well as the existing topographical maps, average slope of Babolrood's riverbed in the upstream and downstream of border conditions of the studied zone was 0.002 and 0.001 (m/m), respectively.

- Flood discharge of the design (with a return period of 100 years) of Babolrood river at the studied bridges was 800 m^3ps.

- Due to narrowness of the flow by the bridge abutments, narrowness and opening coefficients of the flow in the parts were 0.3 and 0.5 respectively.

- Cd coefficient (drag coefficient) and K (defining coefficient of the impact of abutments' shape) are respectively 1.2 and 1.05.

Finally, due to scour studies as well as all given explanations and hypotheses, concerning hydraulic analysis of Babolrood river's computer model at the studied bridges, the following results were obtained. In terms of the water level balance from the designed flood, the studied bridges are safe. Additionally, Froud number in all cases is less than 1, showing that the flow regime is below the critical level. What is more, due to the bridges' position that does not reduce the riverbed's width, scour from flow narrowness is small and there occurs no local scour in the packs.

Also based on the conducted investigates, it is obvious that water's free height compared to the bridge deck in time of flood's flow with a return period of 100 years will be 0.5 meters.

According to the conducted investigates, clearly all three studied bridges are safe in case of flood and scour; therefore, related paired comparisons are brought in Table 22.

According to the results, it is obvious that none of the three bridges will be damaged from flood and scour. Hence none of them is prior to the others.

4.3 Solving the Model with MCDM Method

4.3.1 Solving the Model with ANP Method

In order to solve the model with ANP Method, first the structure was defined in SuperDecision software and since in ANP the relation between the criteria and choices are bi-directional, the weight of each criteria should be obtained in relation to each other. To do so, the FMEA obtains the risk rate of each parameter for different bridges, which is shown in Table 23.

After determining the risk rate for each of the criteria of the different choices, paired comparison of the criteria is performed, the results of which are shown in Table 24, 25, and 26.

After giving weights to the matrices, related to the criteria and choices, the model is solved with SuperDecision and the corresponding results are illustrated in Figure 3.

Table 23. Using FMEA Method to determine the risk rate for each of the criteria in Bridge 1

	RPN for Bridge 1	RPN for Bridge 2	RPN for Bridge 3
Age and bridge exhaustion	400	210	90
Earthquake	270	300	150
Flood	80	80	80
Density of inserted loads	240	150	168

Table 24. Paired comparison matrix of the criteria to each other, based on Bridge 1 choice for solving the model with ANP Method

	Age and Bridge Exhaustion	Earthquake	Flood	Traffic
Age and Bridge Exhaustion	1	5	9	7
Earthquake	$\frac{1}{5}$	1	5	3
Flood	$\frac{1}{9}$	$\frac{1}{5}$	1	$\mathbf{\frac{1}{3}}$
Traffic	$\frac{1}{7}$	$\frac{1}{3}$	3	1

Table 25. Paired comparison matrix of the criteria to each other, based on Bridge 2 for solving the model with ANP Method

	Age and Bridge Exhaustion	Earthquake	Flood	Traffic
Age and Bridhe Exhaustion	1	$\frac{1}{3}$	7	3
Earthquake	3	1	9	5
Flood	$\frac{1}{7}$	$\frac{1}{9}$	1	$\mathbf{\frac{1}{5}}$
Traffic	$\frac{1}{3}$	$\frac{1}{5}$	5	1

Table 26. Paired comparison matrix of the criteria to each other, based on Bridge 3 choice for solving the model with ANP Method

	Bridge ageing and exhaustion	Earthquake	Flood	Traffic
Bridge ageing and exhaustion	1	$\frac{1}{5}$	3	$\mathbf{\frac{1}{7}}$
Earthquake	5	1	7	$\mathbf{\frac{1}{3}}$
Flood	$\frac{1}{3}$	$\frac{1}{7}$	1	$\mathbf{\frac{1}{9}}$
Traffic	7	3	9	1

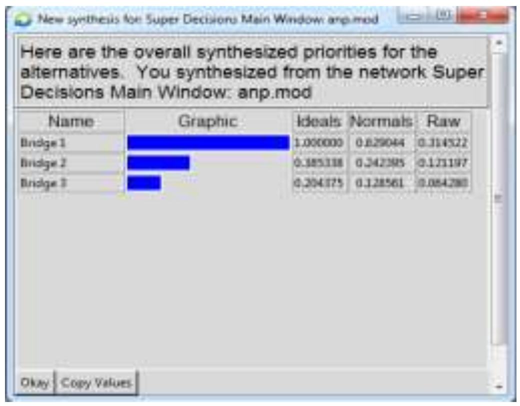

Figure 3. Results of prioritizing the choices by means of Super Decision Software

Table 27. Inconsistency rate of each measure in operating mode

Pairwise comparison matrix	Inconsistency rate
Flood	0
Traffic load	0.055
Bridge life and fatigue	0.07
Earthquake	0.021
Measures with respect to each other	0.041

Table 28. Weight values obtained for bridge risk in operating mode with AHP method

Bridges	Final weight	Priority
Bridge 1	0.493	1
Bridge 2	0.3895	2
Bridge 3	0.1175	3

Table 29. Results obtained from bridge risk prioritization in operating mode using TOPSIS method

Bridges	Final weight	Priority
Bridge 1	0.8657	1
Bridge 2	0.6158	2
Bridge 3	0.5	3

Based on model solution with ANP in Superdecision, clearly the first bridge of Babolsar requires the most repair and maintenance among the bridges of this city.

In order to validate the model, the solved model with the ANP method has been solved with two other methods of AHP and TOPSIS.

4.3.2 Solving the Model with AHP Method

The model will be solved in this section using the AHP method. The inconsistency of each matrix will first be calculated here, as shown in Table 27.

As it can be seen from the results in Table 27, the inconsistency of the matrices can be ignored because their inconsistency values are less than 0.1, and the matrices are acceptable. According to the calculations, the weight of each alternative is calculated based on different measures, and the final weight is then obtained by multiplying the weights of the measures with respect to each other by the corresponding matrix. Table 28 shows the weight values of all the alternatives.

It is observed based on the results obtained from Table 28 that the first bridge in Babolsar exhibits the highest risk in operating mode, and the second and third bridges are rated next.

4.3.3 Solving the Model with TOPSIS Method

For solving the model with the TOPSIS method, maximum and minimum values of data on each column of the matrix are obtained after the weights of the alternatives are calculated and normalized. The positive and negative ideal values for each of the options are then obtained, and the alternatives are finally prioritized through calculation of the relative closeness of each alternative to the ideal one, as observed in Table 29.

According to the results, it is clear that the results obtained from all three methods are the same and we can say that the first bridge has the worst condition among the other bridges.

4.4 Discussion

After analyzing the results, it can be concluded that:

1. In bridge’s operation mode, the factors of earthquake, bridge ageing and fatigue, density of incoming traffic loads and floods are respectively the most critical factors of bridge destruction.

2. In terms of bridge ageing and fatigue, the first bridge in Babolsar has become exhausted from different factors during many years and the possibility of destruction from exhaustion is higher in this bridge than the other ones.

3. Rate of passing traffic load on the first bridge of Babolsar, in accordance with conducted traffic statistics of all the three bridges, is more than the rest and faces the most likelihood of destruction due to its passing traffic. Because of higher age of this bridge and its exhaustion, there should be some traffic limitations on it.

4. Under the influence of earthquake on each of the bridges, the second one will suffer the most damages. It is better to investigate the parts of this bridge in SAP and to detect the ones that in case of their damage are the most likely for the bridge to be destroyed. As a result, the fortification towards the possible damages from earthquake is of great importance.

5. In case of flood in Babolsar’s river, since water passes 0.5 meters from the bridge’s deck in the most critical condition, there will not be any damage to any of the bridges.

6. Upon the conducted studies on bridges risks in their operational mode, it can be seen that the first bridge of the city has the most likelihood of destruction under the influence of the mentioned factors; therefore, since this bridge has aged a lot and has a high traffic volume and due to the fact that it does not have an appropriate structure status, it should be strengthened and fortified or another bridge should be replaced. As this bridge belongs to the landmarks of the city, its destruction will bring about a bad sign for the city, thus there should be more effort on keeping and maintaining it.

5. Conclusion

In this research, the risks during operation of bridges were identified through interviews with experts in the field of bridges. After the involved risks in bridges were identified, the critical risks in the field were determined using the FMEA method given the impossibility to examine all the risks closely. The identified critical risks included the risk of earthquakes, floods, traffic loads on the bridges, and bridge ageing and fatigue. After the critical risks were specified, the three bridges in Babolsar were closely examined against each of the identified risks, and their expected conditions against each other were determined. The AHP, ANP, and TOPSIS multi-criteria decision-making method have been used for evaluating the conditions of the bridges. It was clear according to the evaluation that the first bridge in Babolsar would be in the worst conditions in operating mode.

Since the first bridge plays a very vital role in the structure of the city and its presence is necessary, on the other hand, due to high likelihood for its destruction, and as fortifying this bridge cannot be completely effective, owing to its age, another bridge that will have the same role as this one should be established near the first bridge and on the other side of it, similar to the third bridge in the city; so that the first bridge will be used only for the pedestrians and will be fully kept as a city landmark.

In future research, the model presented in this study can be examined in other cities as well. Furthermore, the optimal period for repair and maintenance of bridges can be determined for reduction of their risks.

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