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Applying Indexing Method to Railway Risk Assessment by Using AHP and Mamdani Fuzzy Algorithm in MATLAB: a case study in Iran, Qazvin-Zanjan Railway

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ABSTRACT

When a cross-country railway is installed and operated, a hazard that would not otherwise be present is introduced. Society generally accepts that the benefits of this hazard for outweigh the increased risk. The title of this essay implies that railway risk assessment is something that should be managed. In order to manage something we must thoroughly understand it. While we will most likely never be able to accurately predict all railway failures, we can however pick out what we believe to be important hazards and factors. In this article after applying the developed indexing method to railway environmental risk assessment, the entire railway route was divided into 34 kilometer intervals and the risk was calculated in each interval. Then the risk number of each interval has been weighted in expert choice software and finally the obtained number by AHP method has been inserted into developed Mamdani Fuzzy Inference System in MATLAB. Using this developed toolbox in MATLAB, it is possible to obtain the fuzzy risk number for each interval which is more accurate. Also all effective risk factors were projected in order to to do the quantitative risk assessment by using GIS. The case study of this article is Qazvin- Zanjan railway in North West of Iran.

Key words: Railway – Risk assessment – Mamdani FIS – AHP – Indexing Method

Introduction

Different methods have been widely used for pipeline risk assessment and management around the world. Studies that have been done so far regarding energy transmission risk assessment conducted by a different approaches, and each of these methods emphasizes on a certain parameter in risk assessment. Risk assessment doesn't have to be a calculation-intensive exercise in probabilistic theory. Such calculations are, after all, based upon probabilities that are of questionable benefits in rare-occurrence scenarios. So the aim of all the attempts to manage the railway or pipeline risk assessment is to deviate from strict scientific procedures in building the risk models. Many articles have been done to manage and assess the risks and hazards in linear projects. Han & Weng propose a qualitative and a quantitative risk assessment method for urban natural gas pipeline network which the qualitative method is comprised of an index system, which includes a causation index, an inherent risk index, a consequence index and their corresponding weights. The quantitative method consists of a probability assessment, a consequences analysis and a risk evaluation (Han, Z.Y., W.G. Weng, 2011). Karimi *et al* propose the indexing method in GIS workspace. In the presented article they apply the quantitative risk assessment by using GIS and overlaying the information layers (Jafari, Hr., *et al*., 2011). In another article titled as risk analysis for oil and gas pipelines, in order to deal with vagueness of the data, the fuzzy logic is employed to derive fuzzy probabilities of basic events in fault tree and to estimate fuzzy probabilities of output event consequences. The study also explores how interdependencies among various factors might influence analysis results and introduces fuzzy utility value to perform risk assessment for natural gas pipelines (Shahriar, A., *et al*., 2012). The implement method in this article is Indexing method which a presented method for pipeline risk assessment. In fact, railway as a linear project has many similarities to gas pipeline risks and hazards. Therefore a developed model based on pipeline indexing method introduced by Mahlbauer can be used for railway risk assessment. Railway risk assessment as an economic transportation system is considerable and a review on statistics of occurred accidents in railways make the necessity of attention, investigation, planning and management of the railways clear.Min An *et al* in article titled as "A fuzzy reasoning and fuzzy-analytical hierarchy process based approach to the process of railway risk info brmation" present the developed risk management system for railway risk analysis using Fuzzy reasoning approach and fuzzy analytical hierarchy decision making process. In the system, fuzzy reasoning approach (FRA) is employed to estimate the risk level of each hazardous event in terms of failure frequency, consequence severity and consequence probability (An, M., *et al*., 2011). Arunraj et Maiti in an article titled as "Risk-based maintenance policy selection using AHP and goal programming" present an approach of maintenance selection based on risk of equipment failure and cost of maintenance. Analytic hierarchy process (AHP) and goal programming (GP) are used for maintenance

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policy selection (Arunraj, N.S., J. Maiti, 2010). Kaya et Kahraman, in an article titled as “An integrated fuzzy AHP–ELECTRE methodology for environmental impact assessment”propose an environmental impact assessment methodology based on an integrated fuzzy AHP–ELECTRE approach in the context of urban industrial planning. In the proposed methodology the criteria weights are generated by a fuzzy AHP procedure and A fuzzy outranking methodology, fuzzy ELECTRE is used to assess the environmental impact generated by the six different industrial districts. Finally, a fuzzy dominance relation (FDR) methodology is used to rank the alternatives from the most risky to the least (Kaya, T., C. Kahraman, 2011). Jozi and Irankhahi use a combination of indexing method and AHP for pipeline risk assessment. By this process classification and qualification of the numerous types of environmental risks would be accessible (Jozi, A., M. Irankhahi, 2010) In Iran, in a comprehensive risk assessment of petro-chemical pipelines, they focused on the assessment of third party damage indicators, incorrect operation, corrosion and design (Jabbari, M., *et al*., 2009). Besides the available resources, the most important source of pipeline risk assessment is the valuable book by Mahlbauer (1999) which is a comprehensive method, trying to assess the risk with considering all the influential parameters.

Methodology:

2.1. Materials:

The case study of this article is Qazvin- Zanjan railway in North West of Iran which passes through the cities of Qazvin, Takestan and Zanjan and also traverses two important environmental protected areas which are Bashgol and Khorasanloo protected areas in two intervals. The most important species in these two protected areas are Canis lupus, Vulpes vulpes and Canis aureus. The railway length is 170 km and goes through the south ranges of Alborz Mountains from east to west direction. Starting point coordinates of the railway are x= 48.365 and y=36.682 and end point coordinates are x=50.037 and y=36.261. The railway passes along the Qazvin-Zanjan main highway but doesn’t cross any river with ecological importance. In terms of geology, the railway has been place in southern zone of Alborz and passes across the volcanic stone formations. The topographical situation of the region is mostly flat.

Methods:

Indexing Method:

Different methods of risk assessment and management are used, such as hazard and operability study, fault percentage analysis, quantitative risk assessment, and optional risk assessment and indexing method (Muhlbauer, W.K., 1999). Each of these methods has its own strengths and weaknesses, but indexing methods are more practical than the others due to faster response, low cost analysis, supportive tool for better decisions and comprehensiveness. (Jafari, Hr., *et al*., 2011; Muhlbauer, W.K., 1999) The base method which has been used in this article is Indexing Method by Mahlbauer. This method has been applied widely in gas pipeline transmission (Muhlbauer, W.K., 1999) and is compatible with linear project conditions in terms of accuracy and required information. According to Graph 1, assessment in this method is divided into two general parts of Impact Index and Index Sum. Preparation of the factors and indexes for railway risk assessment have been had some difficulties. While in some cases, preparation and projection of some criteria were not possible due to limitation of the study, the criterion was removed from the assessment process. In this method, firstly, the data was collected by studying the existing records in railway management structure. It’s an important element to interview with experts involved in different operational parts in order to obtain the final assessment index and also to find the importance weights for AHP method.

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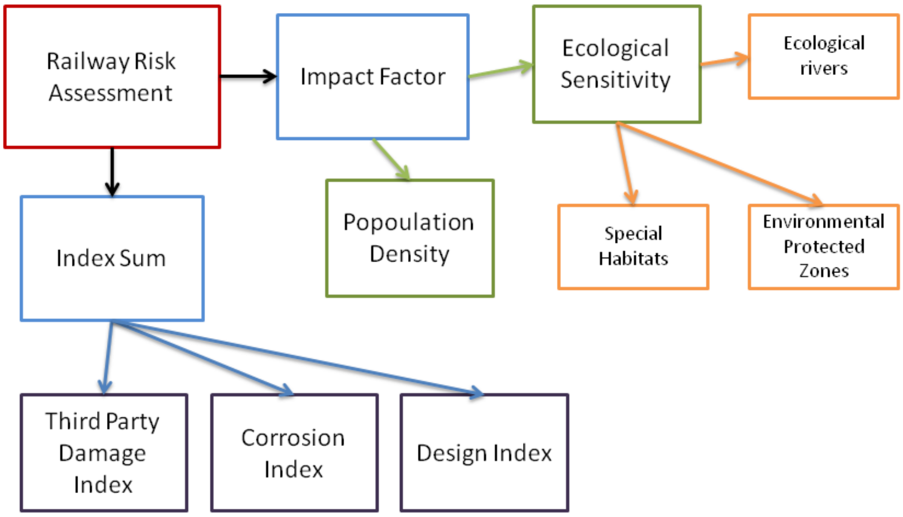

Graph. 1: Railway risk assessment modified model based on Mahlbauer (1999)

In order to achieve the same and comparable results, the entire pipeline railway was divided into 34 kilometer intervals and the risk was calculated in each section.

The AHP Method:

The AHP, which was developed by Professor Saaty in the early 1970s, is a subjective tool with which to analyze, based on a crisp 9-point scale, the qualitative criteria needed to generate alternative priorities and preferences. The AHP enables decision makers to structure complex problems in a simple hierarchical form, and to evaluate a large number of quantitative and qualitative factors in a systematic manner despite the presence of multiple conflicting criteria (Saaty, T.L., 1980). Since the indexes used in this method do not have the same importance, the AHP method has been used to weight the indexes in order to obtain a better and accurate result depending on experts' opinions. In other words, in this step, importance of affective factors on risk potential has been estimated. The hierarchical structure of indexes can be roughly divided into three categories:

1) The highest level: There is only one element factor in this level which is the target analysis, thus, also known as target level.

2) The middle level: This level includes Intermediate links used for the realization of target level. It can be composed of a number of levels, including the criteria and the sub-criteria, thus, also known as criteria level.

3) The lowest level: This level includes a variety of measures and decision-making schemes for achieving the target, thus, also known as scheme level. After the hierarchical structure has been established, a questionnaire based on the proposed structure should be formulated. The main goal of the questionnaire is to compare pairs of element, or criteria, in each level with respect to every element in the next higher level. The nine-point scale is recommended (Dongchuan, S. *et al.*, 2005). After calculating the AHP weights in expert choice workspace, the achieved numbers have been transformed into fuzzy toolbox in MATLAB. For each main index, the diagrams and rules have been developed.

Mamdani FIS in MATLAB:

Several studies using Mamdani FIS have been performed by MATLAB (Lee, D.H., C.H. Juang, 1992; Denhartog, M.H., *et al.*, 1997; Grima, M.A., R. Babuska, 1999). Various fuzzy inference systems have been proposed. The Mamdani FIS is one the most appealing fuzzy methods to employ for environmental assessments. The general characteristics of a Mamdani FIS were described by Alvarez Grima[15]. A Mamdani FIS is composed of the membership functions of input(s), fuzzy if-then linguistic rules, and output membership functions. The general if-then structure of the Mamdani algorithm is given as:

R_{i} : if x_i is A_{i1} and … then y is B_i (for i=1,2,….,k)

Where k is the numbers of rules, x_i is the input variable (antecedent variable), and y is the output variable (consequent variable) (Akgun, A., *et al*., 2012). The calculation procedure of a Mamdani FIS can be given as follows (Alvarez Grima, M., 2000):

1- Compute the degree of fulfillment (α_1) of the input for each rule (i) by considering the degree of membership (μ)

$$\propto_1 = \mu_{Ai1}(X_1) \wedge U_{Ai2}(x_2) \wedge \ldots \wedge \mu_{Ain}(X_n)$$

2- For each rule, derive the output fuzzy set Bi using the minimum t-norm

$$\mu Bi\,(y) = \propto i \wedge \mu Bi(y)$$

3- Aggregate the output fuzzy sets by taking the maximum:

$$\mu_{B'} = \max_{i=1,2,\ldots,k} \mu_{B'}(Y)$$

The final stage of the construction of a fuzzy inference system is to select the defuzzification method. Aggregation of two or more fuzzy output sets gives a new fuzzy set in the basic fuzzy algorithm. Because of its common use in computational simplicity, the center of gravity method is considered for use in the defuzzification process:

$$Y = \int B(y)y\,dy \;/\; \int B(y)dy$$

As it has been mentioned, although Mamdani FIS has been applied to many environmental problems, it has not been applied for environmental risk assessment. Finally, linearity of pipeline project causes problems in spatial and descriptive data collection, documentation and display; therefore it can be solved by applying GIS and quantitative and accurate information (Demers, M.N., 2005; Jafari, H. and S. Karimi, 2005; Salehi Moayed, M. and S. Karimi, 2007). Thus, using GIS tool is essential for solving the above- mentioned problem and subsequent analysis.

Results and Discussion

As it has been mentioned in the methodology, firstly all the parameters were identified and mapped, then scoring was done based on the environmental conditions. Using GIS in mapping and scoring can help the presentation of all probable risks on the map which can be used as tools to develop the existing methods (Jafari, Hr., *et al*., 2011) and can be useful in risk management of railways and prevents the occurrence of probable risks. The defined criteria are reported below:

Third party damage index : this index is presented in table 1 which includes sub indexes such as Minimum rail height and level of region activity such as population centers, agricultural regions and etc, Railway buffer, Patrol frequency and Public education. The total number is obtained by summing all the values for each parameter.

Table 1: Third Party Damage index score in five sections

Sections	1	2	3	4	5
Third index factor	59	70	66	68	68

Corrosion Index: Along the railway route geo electrical examinations have been done above the ground and in depth of 0.5 – 1 meter, with one kilometer interval. Table 2 presents the corrosion levels in terms of different parameters. Since railway corrosion types are different with pipeline corrosion, two kinds of corrosion have been calculated in this modified method which are inner corrosion and outer corrosion. Inner corrosion includes ballast and rail corrosion and outer corrosion includes atmospheric corrosion and soil corrosion.

Table 2: Corrosion index score in five sections

Sections	1	2	3	4	5
Corrosion index	84.4	96	96	90.5	92.6

Design index: this index is divided into two main sub indexes which are the pressure on the rail and Soil movement. Risk score in terms of this index is reported in table 3.

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Table 3: Design index score in five sections

Sections	1	2	3	4	5
Design Index	65	64	65	65	63

These indexes are summed and final score for Index Sum is reported in table 4.

Table 4: Index Sum total score in five sections

Index Sum total score (300 points)	
Sections	Final score
1	208.4
2	230
3	237
4	223.5
5	193.6

After calculating the Index Sum, Impact index is calculated. According to previous studies, Qazvin- Zanjan railway passes through the protected areas of Bashgol and Khorasanloo which are close to the railway in sections two and three. Table 5 shows the Impact index scores in the railway.

Table 5: Impact Index score in five sections

Impact Index	Sections				
	1	2	3	4	5
score	11	4	4	9	12

Finally by multiplying the two main indexes which are Index Sum and Impact Index, Total risk score by indexing method is obtained (Table 6).

Table 6: Total Risk Score in five sections

Sections	1	2	3	4	5
Total risk score	2294.6	920	948	2011.5	2323.2

After calculating the total risk index by indexing method, all the sub indexes have been weighted in Expert choice software and then the derived scores by indexing method are multiplied into each index weight. Table 7 presents all the weighted scores by AHP method.

Table 7: AHP Scores for five sections

Sections / Indexes	1	2	3	4	5
Third Index	27.43	32.55	30.69	31.62	31.62
Corrosion	14.34	16.32	16.32	15.38	15.74
Design	17.94	17.66	17.94	17.94	17.38
Ecological Sensitivity	2.75	1	1	2.25	3
Population Density	0.75	3	2.25	3	0.75

In this study a Mamdani FIS is constructed, the Mamdani FIS for the environmental risk assessment includes a total of 5 inputs which are the mentioned ranges of the railway and all of the inputs are constructed using membership functions (Fig.1). To minimize the uncertainty, a 50 % overlap is applied between the fuzzy sets for each input parameter and triangular membership functions are used for each fuzzy set. In this study a minimum number of the fuzzy set is considered. One of the main parts of a Mamdani FIS is the fuzzy if-then rules. In this study a total 125 rules are used. If-then rules are described only using expert opinions.

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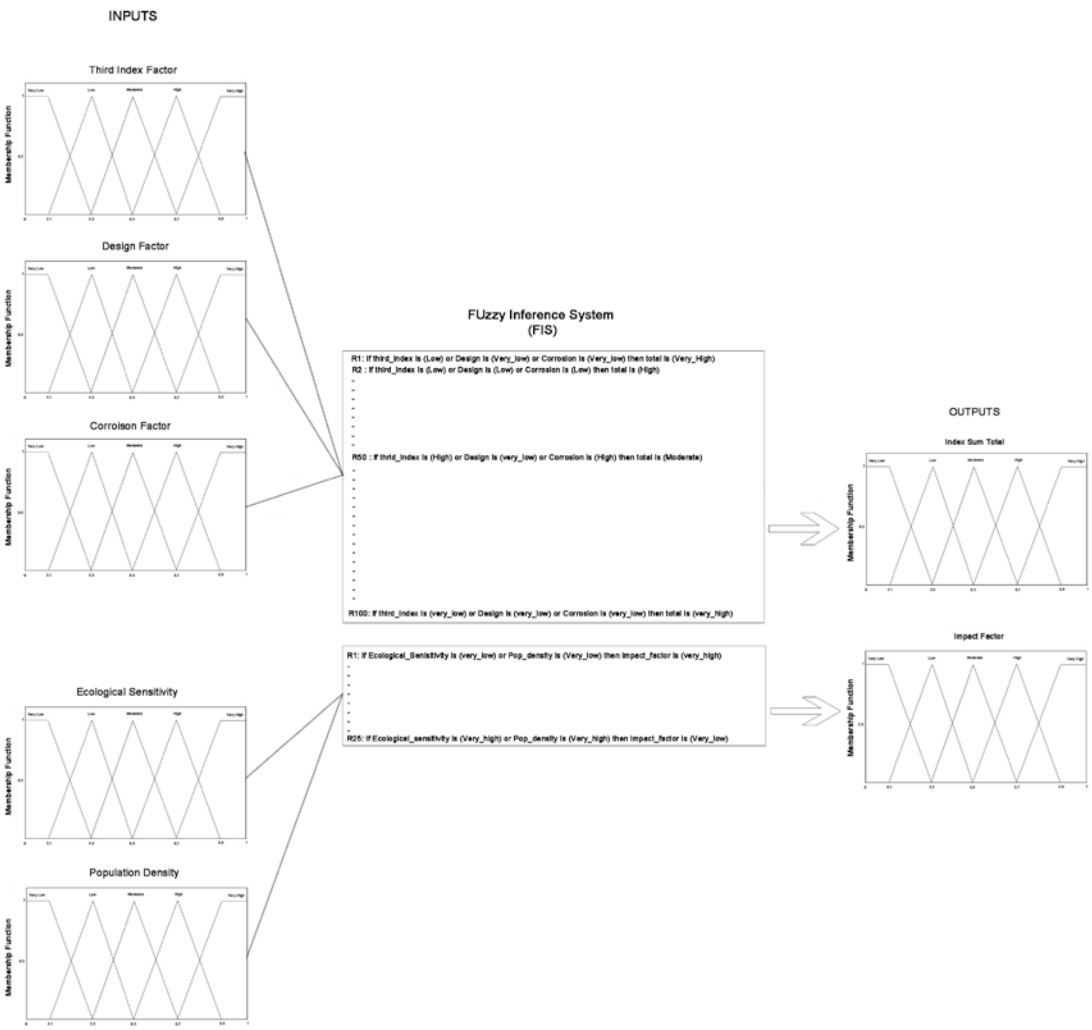

Fig. 1: Mamdani FIS application scheme, followed in this study

After modeling the Mamdani FIS and importing the AHP numbers to the model, table 8 has been produced that shows the fuzzy risk value of each index.

Table 8: Fuzzy Values for Index Sum and Impact Index in five sections

Sections	Index Sum	Impact Index	Fuzzy Value
1	49.4	3.71	183.274
2	50.7	2.97	150.579
3	50.7	3.74	189.618
4	50.7	4.3	218.01
5	50.7	3.71	180.097

Then the fuzzy risk levels have been calculated (table 9)

Table 9: Fuzzy Risk Levels

Fuzzy Risk Value	Fuzzy Risk Level
Less than 150.597	Very high
150.597 – 173.056	High
173.056- 195.533	Moderate
195.533 – 218.01	Low
More than 218.01	Very Low

Finally the risk level for each section has been obtained (Table 10)

Table 10: Risk Levels in five sections

Sections	Risk Level
1	Moderate Risk
2	High Risk
3	Moderate Risk
4	Low Risk
5	Moderate Risk

The difference and distinction between the mentioned method and Mahlbauer method is usage of Geographic Information System (GIS) as a utile method which means all the mentioned indicators and criteria were projected and the calculations were performed spatially rather than statistical operations. In this article, all the factors which have the ability to be documented are imported into GIS and after preparing all the information, layers are calculated by using GIS Raster Calculator. Fig.2 shows the risk levels in the case study railway.

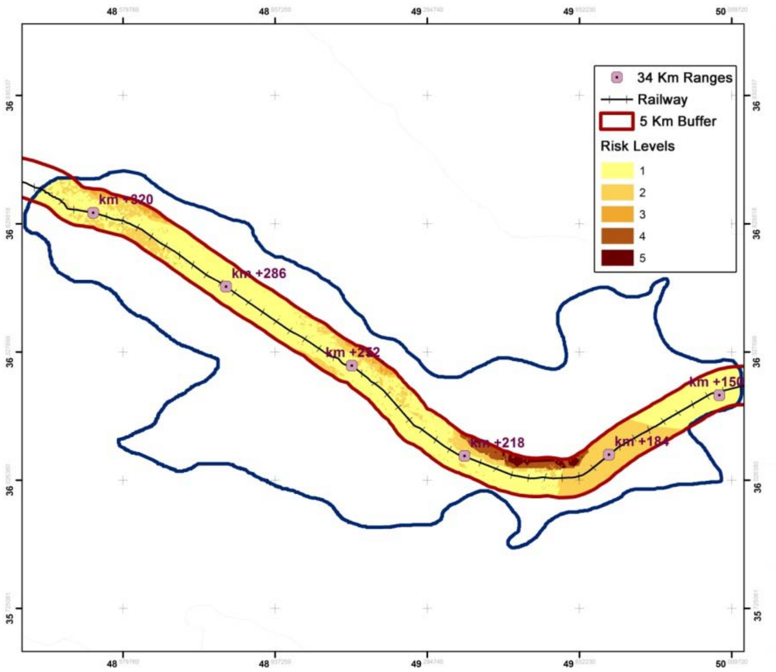

Fig. 2: Obtained Risk levels of the case study railway in GIS

Conclusion:

After calculating each interval risk, finally the risk numbers were accumulated and the whole fuzzy risk score for five sections have been presented in table 10.It is obvious by the results that the railway has different risk levels and moreover the entire project has the environmental risk potential due to project essence. In other words it can be said in this way that the whole railway has the basic risk but the classified intervals show the accurate risk levels for each interval. Table 9 shows the fuzzy risk levels in the railway. It can be seen in this table that the most risk level belongs to the section closer to the environmental protected areas. It can also be concluded that although the risk amount is not the same in all parts of the railway, it is important to monitor the whole railway to prevent the unpredictable hazards in future but with more emphasize on the sections with higher risk levels.

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