

Utilization of Soft Computing for Risk Assessment of a Tunneling Project Using Geological Units

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Abstract

Soft computing is one of the most efficient tools for analysing risk taking in civil engineering projects. Therefore, in this paper, using Fuzzy C-means (FCM) technique as one of the most efficient and important classification methods in the area of soft computing, risk in the tunnelling project was evaluated and analysed. For this reason, considering three mechanical and physical parameters influencing the design and execution of the tunnelling project including overburden (H), internal friction angle (φ) and cohesion (C), geological units were classified along the project's route. The present study has been conducted on the third section of Ghomrud tunnel as one of the greatest tunnelling projects in the centre of Iran. Results obtained from the evaluation of geological units along the tunnelling project's route after the validation of drilling rate index's results show the appropriate evaluation of the project's risk through fuzzy clustering technique.

Keywords: Soft Computing; Risk Analysis; Tunneling Project; Fuzzy C-Means Technique; Drilling Rate Index (DRI); Geological Units.

1. Introduction

Nowadays, with an increasing growth in the global science and technology, dealing with more complex and vague problems is inevitable. Therefore, the need for methods which understand complex and ambiguous problems is felt more than before. Neural networks, meta-heuristic methods, fuzzy neural networks and fuzzy logic are techniques of soft computing which have various applications in optimizing and solving problems in different sciences [1-5]. Several optimization approaches were used by Yagiz & Karahan (2015) for estimating tunnel boring machine (TBM) performance [6], including Differential Evolution (DE), Hybrid Harmony Search (HS-BFGS) and Grey Wolf Optimizer (GWO). From among soft computing methods, the fuzzy logic has a special place due to its very appropriate ability and flexibility in modeling uncertainties in linguistic expressions and problems in terms of mathematical relations [7-9]. The risks of Alavian dam construction operations was investigated by Haghshenas et al (2016) using the fuzzy multiple criteria decision making (FMCDM) technique [10]. The protection of the body slope of the reservoir dam in Iran was evaluated by Yousefi Rad et al (2012) and analyzed through Fuzzy analytical hierarchy process [11].

Risk management is one of the issues having complexity and uncertainty in the evaluation and investigation of problems due to the influence of different factors. In the recent decade, with the increase of construction projects, the evaluation and analysis of projects' risks have led to the correct understanding of the process of projects and a significant reduction in financial losses and casualties. There are different methods for the study and management of risk, including the fault tree method, meta-heuristic algorithms, Monte Carlo simulation technique and multi-criteria decision-making methods [12-19]. The application of Monte Carlo simulation for risk assessment [20] was evaluated

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by Yun-Fu (2008). The optical investigations for compartment fire risk analysis were carried out by Siu Kui (2007). They used Monte Carlo simulation as soft computing method in their study [21].

Therefore, in this study, the risk in the tunneling project on the third section of Ghomrud tunnel has been investigated and evaluated using one of the most practical instruments of soft computing, the fuzzy clustering technique. Classification and evaluation of geological units is one of the risk management methods in tunneling projects. Therefore, considering physical and mechanical properties of geology along the project's route, three influential factors in the process of design and execution of project are selected respectively as follows: Overburden (H), internal friction angle (ϕ) and cohesion (C). Then, after the required analyses, results are validated with drilling rate index (DRI) obtained through the execution of project. Finally, results show an appropriate match with experimental results, indicating the proper application of fuzzy logic in the risk analysis.

In fact, the goal of geological units' classification is addressing the most important hazards and suitable prediction of project based on the limitation of resources. Therefore, using fuzzy clustering technique based on uncertain systems, a high level of precision in data analysis can be obtained.

2. Ghomrud Tunnel

In recent decades, with the increase of population, the need for the growth of construction projects has led to the increase of investments in the infrastructures of Iran. One of the important infrastructures in the area of construction is tunneling projects which have a significant role in the growth of industry, transportation, supply and transfer of water. Therefore, the present research on the third section of Ghomrud tunnel has been conducted as one of the greatest tunneling projects. Evaluation of the project's risk in order to consider the design and execution conditions in tunnel due to its location in Sanandaj-Sirjan zone which is one of the most risky geological zones in Iran has a special place. The tunneling project's route is located in six geological units with nine different geological properties. Figure 1. shows the location of project's execution [22-24].

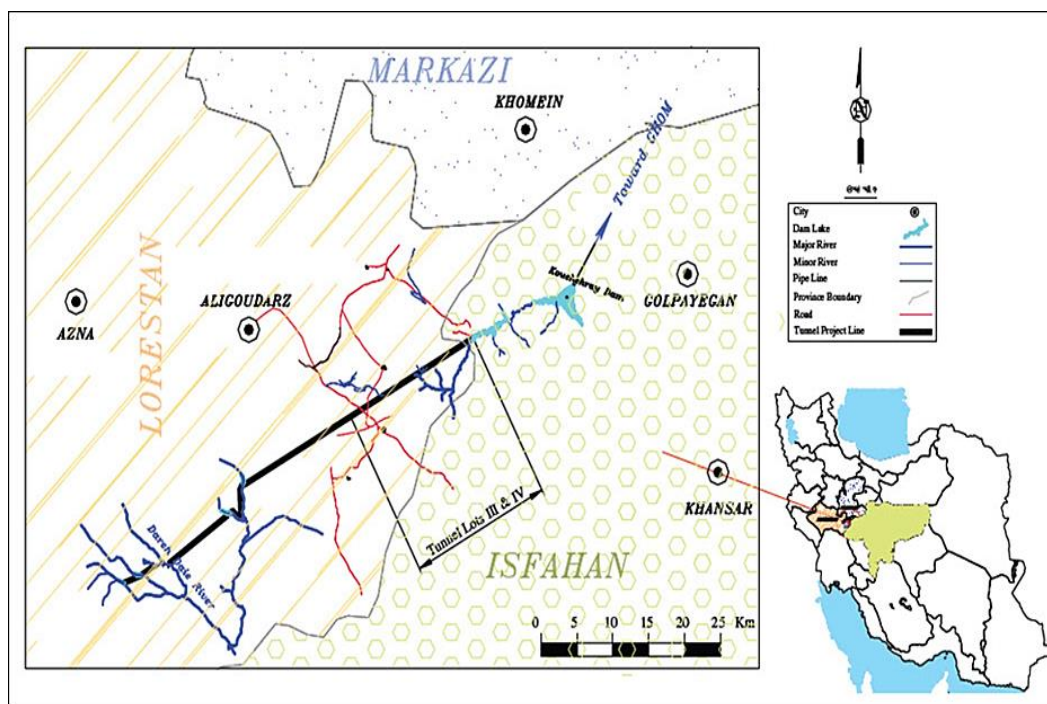


Figure 1. Location of the Tunneling Project [25]

Technical specifications of tunnel include: tunnel length is 36 Km and excavation is done by an EPB-TBM. Excavation diameter, final diameter and excavation volume are 4.69 m, 3.8 m and 195000 m³, respectively [26]. In addition, Table 1. shows physical and mechanical parameters of geological units along the project's route. Considering information in Table 1, there are six geological units with nine different geological properties along the project's route. According to the important role of strength in geological units, the internal friction angle (ϕ) and cohesion (C) are involved in geological engineering characteristics classifications. However, Overburden (H) is one of other different effective factors for assessment of geological engineering characteristics in tunneling project, because it has key role in value of loading and tension [27].

Table 1. Mechanical Properties and Drilling Rate Index (DRI) [28]

Geological units	Lithology	Geological engineering characteristics	Overburden (H)	ϕ (Degree)	C (MPa)	Drilling rate index (DRI)
KI	Lime	Massive limestone	600	24	4.46	60
KII	Clay – Calcareous Sandstone	Limestone laminate	600	28	3.2	60
KIII	Calcareous units	Crushed zone	600	24	1.7	60
JI	The Frequency of limestone, shale and sandstone	Sandstone (a)	350	26	2	50
		Shale-Slate (b)	350	42	3.13	50
JII	The Frequency of graphite schist, quartz-schist, quartzite	Schistosity developed (a)	200	23	1.85	50
		Schistose (b)	200	24	1.9	50
		Unknown layer (c)	200	47	3.71	50
JIII	Metamorphic units	Crushed zone	450	22	1.97	50

3. Fuzzy Clustering Technique

In a paper under the title "theory of fuzzy sets", the basis and foundation of fuzzy logic have been provided by Zadeh in 1965 [29]. The fuzzy logic is a multivalued logic which is used as a powerful and flexible instrument contrary to the classic logic for modeling certainties and uncertainties and linguistic expressions in terms of mathematical relations [30-33]. One of the applications of the fuzzy logic is fuzzy classification. Fuzzy C-means (FCM) method was proposed by Bezdek based on the generalization of Hard C-means (HCM) clustering method [34]. High convergence and accuracy are among advantages of this algorithm. This algorithm has been proposed in 4 steps based on the iterative optimization, including:

In the first step, the number of clusters c is determined. The numerical value of c is always larger than or equal to 2 and smaller than or equal to n (number of samples). After determining the number of clusters (numerical value of c), the value of weighting factor m' is determined. The weighting factor determines the amount of fuzziness in the clustering process. $U^{(0)}$ is guessed as the initial partitioned matrix and the number of each step or iteration of this algorithm is determined with r value.

Second and Third Steps: in the second step, the center of clusters ($V_i^{(r)}$) is calculated per iteration. Then, in the next step, using equations (1) to (5), the partitioned matrix for r th iteration is updated as ($U^{-(r)}$) [35].

$$\mu_{ik}^{(r+1)} = \left[\sum_{j=1}^c \left(\frac{d_{ik}^{(r)}}{d_{jk}^{(r)}} \right)^{\frac{2}{m'-1}} \right]^{-1} \quad \text{for } I_k = \phi \tag{1}$$

$$I_k = \{i \mid 2 \leq C < n; d_{ik}^{(r)} = 0\} \tag{2}$$

$$\mu_{ik}^{(r+1)} = 0 \quad \text{for all classes } i \text{ where } i \in \tilde{I}_k \tag{3}$$

$$\tilde{I}_k = \{1, 2, \dots, c\} - I_k \tag{4}$$

$$\sum_{i \in I_k} \mu_{ik}^{(r+1)} = 1 \tag{5}$$

Where, $\mu_{ik}^{(r+1)}$ shows the membership degree of k th data in the i th cluster for $r + 1$ iteration of the algorithm. In addition, d_{ik} shows the Euclidean distance between the center of the i th cluster and k th data.

Then, in the final step, the conclusion step of clustering or in other words, the accuracy of algorithm is investigated. If Equation 6. is satisfied, the result of clustering will reach a desired optimization. Under such condition, calculations can be stopped. Otherwise, the second step and its calculations are evaluated. In the following relation, ϵ_L shows the accuracy level of algorithm

$$\|\tilde{U}^{(r+1)} - \tilde{U}^{(r)}\| = \epsilon_L \tag{6}$$

4. Modeling and Discussion

This study evaluated 9 different kinds of Geological engineering characteristics by laboratory and field studies. In field studies, the drilling rate index (DRI) is measured, while laboratory tests are provided with four important physical and mechanical characteristics of rocks as clustering optimization for risk analysis. In the present study, for the modeling and classification of data in Table 1, first, data are collected and normalized. Then, after the preparation of the pseudo-code of FCM algorithm in MATLAB, the algorithm's control parameters are adjusted in order to have a desired optimization, including:

The weighting parameter of $m' = 2$, maximum iteration of 100, minimum acceptance precision of $\epsilon_L = 0.00001$ and the number of clusters $c = 2$.

In the next step, the normalized data are called in the algorithm as input data and after the analysis conducted in the 9th step, the algorithm is converged and the condition of minimum acceptance precision is satisfied; therefore, the algorithm's operation is stopped. Classification and investigation of geological units are one of the most important sections in the project management and prediction. Results of evaluation and optimization of data are shown in Tables 2 and 3. Furthermore, Figures 2 and 3. show the process of cost function's optimization in the algorithm and the location of data.

Table 2. Optimization and Classification of Risk by Fuzzy Clustering Technique

Geological units	Optimum partition		Classification
KI	0.841	0.159	First Class
KII	0.981	0.019	
KIII	0.75	0.249	
JIII	0.518	0.482	
JI (a)	0.121	0.879	Second Class
JI (b)	0.371	0.629	
JII (a)	0.086	0.915	
JII (b)	0.073	0.927	
JII (c)	0.325	0.675	

Table 3. Distance of Criteria from Centers of Clusters

Criteria	First cluster	Second cluster
C ₁	0.925	0.456
C ₂	0.574	0.615
C ₃	0.695	0.514

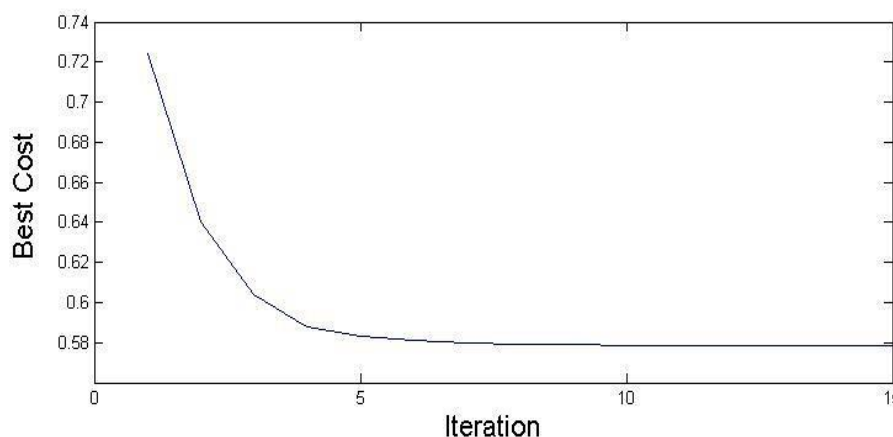


Figure 2. The Best Cost of Optimization Process by FCM

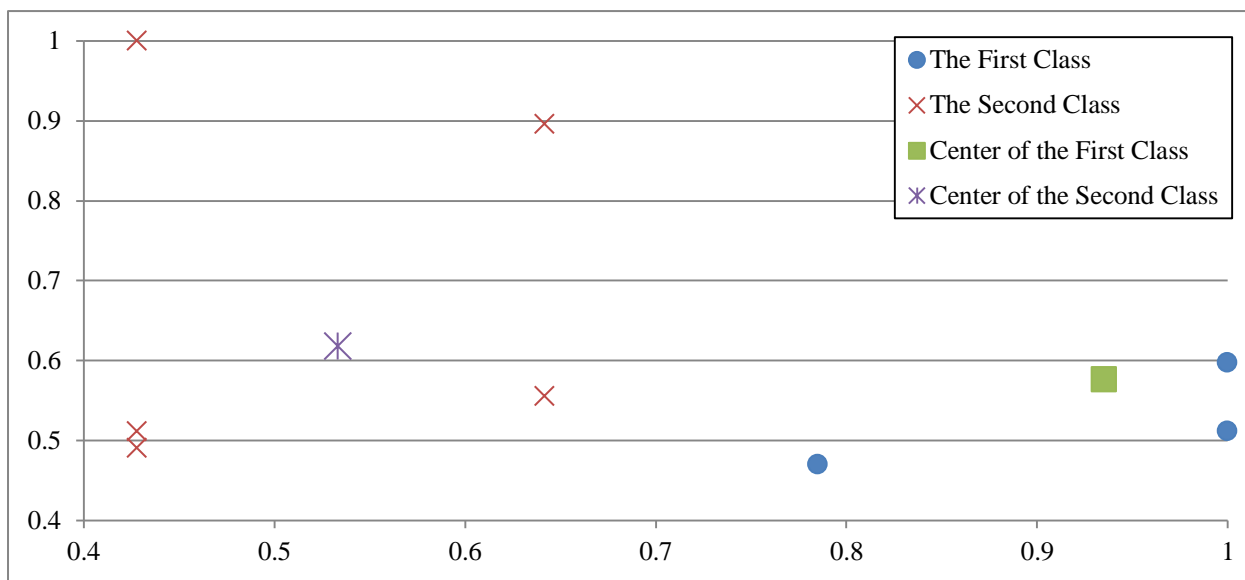


Figure 3. The Positions of Each Data and Centers of Clusters

In each study, validation is an important and fundamental section of research. Therefore, in the present paper, after the evaluation and analysis of data, results are validated with drilling rate index (DRI) based on Table 4. Only in section JIII, this classification is located in a more powerful section opposed to DRI. One of the reasons of the location of this section in another class is the possibility of occurrence of error in experimental measurements, but based on the analysis results, FCM algorithm places this section in the first class and it is accurately validated based on the number of other classifications with DRI. Of course, if error is also due to the algorithm, the algorithm is a desired estimation in the classification of other geological units and the error is highly acceptable. Thus, based on the validation of data, it is determined that FCM technique is a reliable and efficient method for the classification of geological units considering the tested physical and mechanical properties. In addition, based on the analyses conducted, it is determined that the project's route is located in two strong and weak regions in terms of geological risks. In the risk management, risk reducing methods are introduced for inevitable risks. Therefore, considering the inevitability of geological risks in the tunneling project of the third section of Ghomrud tunnel, some suggestions can be provided in order to reduce geological risks, including: the increase of reliability coefficient in the design of tunnel, the increase of the executive team's safety and application of appropriate instruments and facilities with drilling condition in weak zones.

Table 4. Result of Classification by FCM Compared to DRI

Classification of Geological Units	Drilling Rate Index (DRI)	
First Class	KI	60
	KII	60
	KIII	60
	JIII	50
Second Class	JI (a)	50
	JI (b)	50
	JII (a)	50
	JII (b)	50
	JII (c)	50

5. Conclusion

In recent decades, concurrent with the increase of vague and uncertain problems, the application of soft computing methods also increased. One of the most important methods of soft computing is the theory of fuzzy sets with the ability of solving large-scale problems with many variables. Furthermore, important problems in risk management

often have many influential variables and the ability of full match with fuzzy concepts. Therefore, in this paper, using fuzzy clustering technique, geological units of the region in the execution of tunneling project in the third section of Ghomrud tunnel are evaluated. The obtained results are validated with drilling rate index (DRI), indicating the high ability of FCM algorithm in the classification of geological units in tunneling projects and an appropriate provision of the condition of the region for evaluating the risk management in the project.

6. References

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