IJTE, Vol. 10, No. 4, Spring 2023, pp. 1253-1266
Research Paper

A Multi-Attributive Border Approximation Area Comparison Solution for Risk Assessment of Rock Falls in Rural Mountainous Roads

Morteza Asadamraji[1,*]

Received: 2023/02/10 *Accepted: 2023/05/06*

Abstract

Designing and exploitation of mountainous roads is commonly comprised of numerous risk during their life time. The most expected danger relatively is rock fall occurrence. This dangerous phenomenon causes different issues for transportation, such as road closure and disrupt transportation or delay in travel time.
Studying the contingency of the abovementioned features, foremost rock falls and landslide, is generally conducted through field inspection beside data gathering and utilizing aerial maps and photos. Regarding to that, safety audit datum, slope stability, weather information, topography and surveying data, geological definition of region, etc. are all essentially required to perform a mathematical ranking procedure for the sections of the case study.
As a case study, 9 stations were selected in Yasuj – Semirom road which divided the path to different sections. The stations were identified due to the resembling properties of sections such as sight distance, annual traffic, side slope, weather conditions, etc. Using the MABAC method, the sections that had a greater distance from the boundary of the similarity zone as a determining index had a higher risk. The most important parameters in the risk of sections were slope heights, rock fall frequency and sight distance.
The results of this study can be used to improve the safety of mountain road sections, especially in conditions of budget constraints.

Keywords: Mountainous road, Risk, rock fall, prioritization, Ranking

[*] Corresponding author E-mail: m_asadamraji@sbu.ac.ir
[1] Assistant Professor, Department of Geotechnics and Transportation, Faculty of Civil Engineering, Water and Environment, Shahid Beheshti University, Tehran, Iran

1. Introduction

Natural disasters are events which roads are highly prone to that which are independent to country development. Hence, effective governmental risk management programs are required in order to reduce financial losses and casualties.

The risk of avalanches and landslides are quite high in mountainous roads with higher risk of the latter one. In order to reduce abovementioned-caused hazards, first, dangerous points has to be identified and studied, and next, the points get prioritized for safety activities (Smith, 2013).

A region's disaster probability study is done by data gathering, field inspection, and aerial photos. Surveying local people about slopes and previous falls could also be helpful. Gathering historical data for aggregate time intervals is suggested and as a result, disaster-prone places could be identified. Another way of finding risky segments is analyzing field inspections and effective factors such as vegetation, slope, and slope degree in height. Principal factors of estimating slope falls risk are as following:

- The height of mountainside
- Geological characteristics
- Vegetation-free land
- Slope of more than 20-60 degrees (Burns, 2006. Grêt-Regamey & Straub, 2006).

Most challenging difficulties of risk prioritization is lack of data and considering not all effective factors (Vybiral et al. 1995). In this paper, first, prominent parameters of rock fall risk on a mountainous road are identified and weighed by experts. Next, road segments' risk is ranked by multi-attributive border approximation area comparison Solution.

This paper aims to prioritize rock falls risk areas in different segments of a mountainous road. The contribution of the research is in the use of distances to the similarity area in road risk assessment, which has not been used in research so far. The problem so far was that single criteria were used in the decision to allocate funds to improve the safety of mountain roads, or it was a personal decision, but this problem can be solved with the MABAC method. In addition, the combination of road and geological parameters has been less frequently used in mountain road risk assessment research.

2. Literature Review

Hoang Tien et al. compared the multi-criteria decision making methods using the same data of standardization method. In two different examples, the combination of multi-criteria decision-making methods with weighting ones for ranking alternatives were demonstrated and showed that regardless of the weighting method, usually multi-criteria decision-making methods determine the same best solution (Dung & Nguyen, 2022).

In this regard, previously used methods and parameters are studied in this section in order to select the best ones for prioritizing.

2-1 Rock Fall Risk Evaluation Factors

There are several factors and methods of Rock falland avalanche risk evaluation, as follows: (Rajaee Baghsorkhi et al. 2022)

a) Rock fall risk evaluation using maps and geographical coordinates:

In south Europe and United States of America, a GIS-based method is used that all Rock fall points are identified using field inspections and aerial photos, what layers made on a base topographic map in exact dimensions. The most important considered factors are slope instability, regional topographic information, and event frequency. More information and event frequency means more risk which is shown by color or thickness on the map (Jamieson & Stethem, 2002). Also, Barbolini et al. suggested a GIS-based approach for modeling risk of Rock fall(Cappabianca et al. 2008), Alike the study of Rajaei et al. which modelled, mapped and evaluated factors affecting the occurrence of snow avalanches and risk management in Shemshak region (Rajaee Baghsorkhi et al. 2022) . Besides, the prediction of avalanches in the study of Duriveic et al. was based on the use of geographic information systems (GIS), remote sensing, and multi-criteria analysis—analytic hierarchy process (AHP), in which five indicators (lithological, geomorphological, hydrological, vegetation, and climatic) were processed and 14 criteria were analyzed (Durlević et al. 2022).Yarian et al. expoigatated a few novel hybrid models based on GIS for snow avalanche susceptibility mapping (Yariyan et al. 2022).

Aneli et al. aimed to define an indicators-based methodology for determining a synthetic natural risk index, which represents the degree of territorial exposure to multiple natural disasters such as landslides using MCDM methods (Anelli. et al. 2022). In the study of Singh et al. potential avalanche formation zones have been generated using Analytical Hierarchical Process (AHP) of multi-criteria Decision (Singh et al. 2018).

Handbook of Himalayan Ecosystems and Sustainability demonstrated Rock fall susceptibility modeling in the Indo-China border area used the geographic information system and the multi-criteria decision-based analytical hierarchy process model (Pandey et al. 2015).

b) Rock fall risk evaluation using expertise

Rock fall risk evaluation using observation and simple calculations was suggested in 2005 and Slope fall-prone slopes were identified and categorized by analyzing hundreds of kilometers of west USA and Canada roads. Slope was the most prominent parameter in this method (Zischg et al.2005).

c) Rock fall risk evaluation using historical data

Event frequency and consequent incidents are studied in this approach. The data is usually considered as Rock fall frequency or slope fall-caused fatalities in 3-year time durations (Rheinberger et al. 2011).

d) Rock fall risk evaluation using other parameters

There are some other methods used for Rock fall risk evaluation. For instance, Ahmed et al. introduced a criterion for mountainous roads using a Bayesian model which rank Rock fall risk of segments (Ahmed, et al. 2011). Other criteria are also used in different researches such as:

- Road weather (Kristensen et al.2003)
- Retaining structures along roads (Foster, 2012).

Moreover, Ganapathy studied Rock fallrisk parameter in different roads of India in 2010 (Ganapathy et al. 2010). However, there is no practically and mathematically effective risk assessment model for Rock fall risk evaluation in other countries rather using many parameters. Despite of other kinds of landslide, slope fall-prone prioritization has been studied rarely and the only used method is AHP. There are many other ranking approaches such as RHRS which has been used since 2003 which was improved by Andrianopoulos et al. in 2013. Landslide risk in mountainous roads is estimated considering geological, regional, climate, and general conditions of roads (Andrianopoulos et al 2013). Straub et al. also identified and weighed landslide sources (Straub et al. 2008). Mignelli et al. evaluated landslide risk on different segments roads and also, considered prevention methods and retaining structures in their model (Mignelli et al.2014). Machine learning techniques were also used in spatial modelling of snow avalanche susceptibility in Akay's study, the belief function values of snow avalanche conditioning factors extracted from snow avalanche inventory data exploring geographical information system software (Akay, 2021).

Furthermore, the vast majority of previous studies on accidents' causes' identification mainly focus on three significant risk factors and from those, different safety-related areas of research have been created:

(1) The human factor and vehicle conditions.

(2) The influence of environmental conditions, and

(3) Factors related to technical design and administration problems for highways (Yu et al. 2019).

Reason et al. developed the Driver Behavior Questionnaire (DBQ) in the University of Manchester, one of the most widely used instruments to measure driver behavior related to collision risk. This instrument is attributed to a questionnaire that has been applied and adapted to suit the context of different countries; (Reason et al. 1990.Stanojević et al. 2018) mostly applied the instrument in countries in south-eastern Europe;

Rivera and Mendoza mention that it is possible to measure the effectiveness of safety interventions through the analysis of accidents, by ranking the effectiveness in different criteria, such as reduction of accidents, reduction of deaths, and reduction in costs, among others (Rivera & Díaz, 2009).

For example, Justo-Silva and Ferreiracarried performed a research that incorporated accidents costs into maintenance planning processes and pavements rehabilitation (Justo-Silva & Ferreira, 2019). Nadimi et al. presented a method for calculating time to collision based on driver characteristics, environmental conditions, the type of preceding object and the microscopic traffic parameters of the subject vehicle based on an adaptive neuro fuzzy inference system and motion mechanics (Nadimi et al. 2022).

Several studies have been carried out to analyze the empirical relation between road accidents and the different variables of geometric road design, such as degrees of curvature, vertical slopes, and the balance of vertical and horizontal alignments, using different statistical models (Miaou & Lum, 1993. Milton & Mannering, 1998. Vayalamkuzhi & Amirthalingam, 2016. Gooch et al. 2016). For instance Li and Wu presented the intuitionistic fuzzy cross-entropy distance and grey correlation analysis method (Li & Wu, 2016). Sheikholeslami et al. Studied the effect of hazard properties on driving accident likelihood, which was investigated in a condition that enough recognition and reaction time window were available for the driver to provide a ceteris paribus experiment (Sheikholeslami et al.2020).

Chen, Cheng, and Lan built the TOPSIS method for MCDM through similarity measures under their major studies about intelligent systems in rural roads safety (Chen et al, 2016). Asadamraji focused on prioritization of practical projects of intelligent transportation systems with consideration to budget shortfall and its basis for decision-making of those involved (Asadamraji, 2022).

Khan and Lohani defined the similarity measure of intuitionistic fuzzy sets through the distance measure of bounded variation (Khan & Lohani, 2016). Lubis et al. used Mabac method to study the investment selection in transportation subsector to choose the right and proper way of improving safety (Lubis et al.2022).

In the literature review, the combination of road variables and rock mechanics in combination with the criterion of distance to the border of similarity has not been used.

3. Rock Fall Risk Assessment in Different Segments of a Mountainous Road

The parameters are chosen considering the ones mentioned in the literature and adding some extra ones such as road and traffic parameter.

a) Slope height (mountainside height) and its angle

In soil embankments decreasing slope angle increases the factor of safety nearly linearly while a decrease in height increases the factor of safety at a parabolic rate, while the risk of disserving and undamaging would be remarkably more in higher elevations.

b) Frequency

Historical data is always a basement for prioritizing safety activities on roads. Three different classes are identified for considering this parameter in the model:

- Rock fall occurred in more than 10 years ago (medium risk)
- Rock fall has occurred since 3-10 years ago (high risk)
- Rock fall has occurred in last 3 years (very high risk)

c) Hillside slope

One of effective factors is hillside slope that steeper the slope, larger driving force of rocks occurs, which causes slope fall. Angle of more than 30 degrees increases Rock fall risk.

d) Road traffic

More vehicles passing the slope fall-prone segment, more probability of financial losses and casualties is expected. Hence, road traffic is identified as the last effective factor of Rock fall risk ranking.

e) Friction of rocks

An understanding of frictional sliding between rocks is an important pre-requisite to understanding of Rock fall mechanisms.

f) Sight distance

The stopping sight distance is one of the factors affecting driving crashes, either with vehicles, pedestrians, fixed or unanticipated objects like fallen rocks.

g) Geological properties

Slope stability is ultimately determined by two factors: The angle of the slope and the strength of the materials on it. Slope failures occur when driving forces overcome resisting forces. The driving force is typically gravity, and the resisting force is the slope material's shear strength, which is mainly related to the geological properties of region.

4. Rock Fall Risk Evaluation Method in Mountainous Roads

The flowchart shown in figure 1 is suggested based on MABAC method. As shown in figure 1, the first step is identifying risk factors which are geological properties, road traffic, slope length and height, historical data (frequency of occurrence), friction of rocks, and sight distance.

MABAC method like any other MCDM solution is sensitive to changes in weight of criteria. It refers to statistical adjustments that are made to survey data after they have been collected in order to improve the accuracy of the survey estimates. Shannon's entropy method is one of the various methods for finding weights discussed previously. Studies found that the Entropy method provides higher accuracy compared to any other weighting method, such as the PCA method. Also it is claimed that the Entropy method demonstrated to assess the weights of the higher dimension dataset was higher sensitivity than the lower dimensions. A weighted average is sometimes more accurate than a simple average. In a weighted average, each data point value is multiplied by the assigned weight, which is then summed and divided by the number of data points. For this reason, a weighted average can improve the data's accuracy.

According to the literature, at least 10 are enough for questioning and in this study, 50 experts negotiated over selecting the affecting factors which were derived from literature and researching the phenomenon’s incentives. The exerts were specialized in transportation, mechanics, and geology. Among various factors which were identified in previous studies, the 7 most important ones were candidate for the calculation procedure.

In the weighting step, Shannon entropy method was utilized by experts in geology, environment, traffic and road design, etc. science as discussed previously, and pair-wise comparison matrix checked out either which are shown in table 1 and its diagram is shown in figure 2. The weights were compared with previous researches and no significant difference was observed which validates the weights of table 1.

In the next step, surveys and data gatherings were processed with the aim of the attaining the most remarkable and reliable datum to form a database with the participation of various experts in field inspection.

Prioritization by MABAC decision making technique comes after. The technique includes following phases:

- Identifying factors (which was done previously)
- Creating decision matrix (Similar to any other MCDM method)
- Calculating weighted normalized matrix (V)

$$n_{ij} = \frac{X_{ij} - X_i^-}{X_i^+ - X_i^-} \quad \text{Positive Criteria}$$
$$n_{ij} = \frac{X_{ij} - X_i^+}{X_i^- - X_i^+} \quad \text{Negative Criteria} \tag{1}$$

$$V_{ij} = W_j + (n_{ij} + 1) \tag{2}$$

- Calculating the values of border approximation area (BBA)

$$g_i = \prod (v_{ij}) \tag{3}$$

$$G = [g_1, g_2, \dots, g_n] \tag{4}$$

- Calculating the distance between alternatives and BBA.

$$Q = V - G \tag{5}$$

$$A_i = \begin{Bmatrix} G^+ & q_{ij} > 0 \\ G & q_{ij} = 0 \\ G^- & q_{ij} < 0 \end{Bmatrix} \tag{6}$$

- Summation the values of each alternative's distance
- Ranking the alternatives

Segment risk is estimated by the criterion of Si. Higher Si means higher priority of the segment.

$$S_i = \sum_{j=1}^{n} q_{ij} \quad \begin{matrix} j = 1,2,\dots,n \\ i = 1,2,\dots m \end{matrix} \tag{7}$$

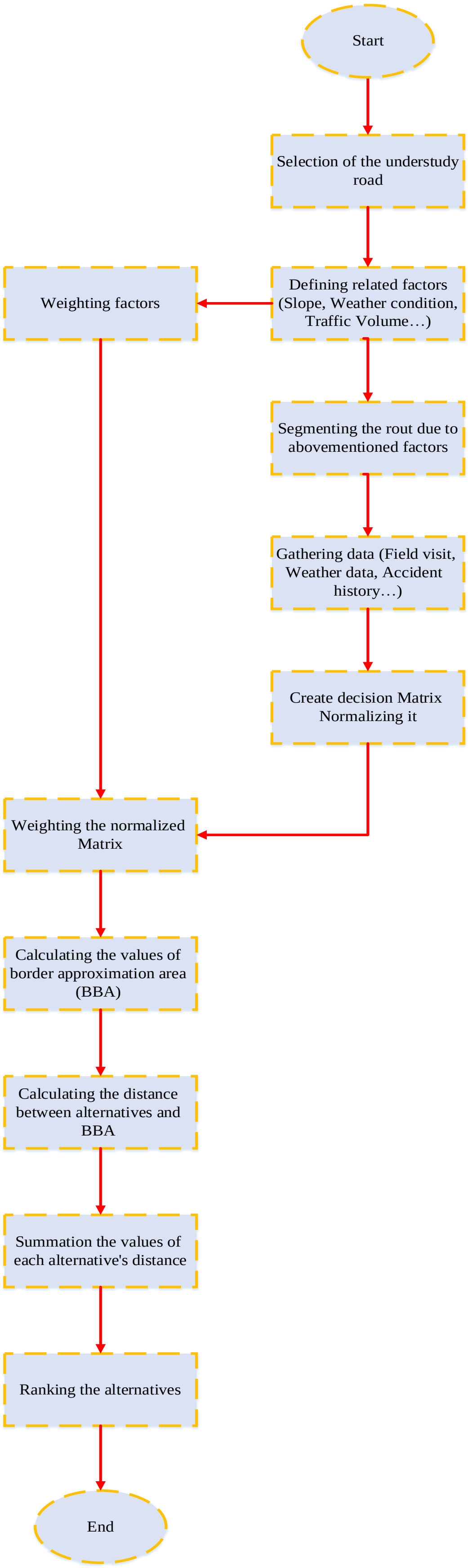

Figure 1. Rock fall risk prioritizing flowchart on mountainous roads

Table 1. Risk factor weights values

Factor	Frequency	Sight distance	Road traffic	Friction of rocks	Geological properties	Slope length (m)	Slope height (m)
Weight	0.3895	0.1428	0.0006	0.0111	0.0032	0.0511	0.4016

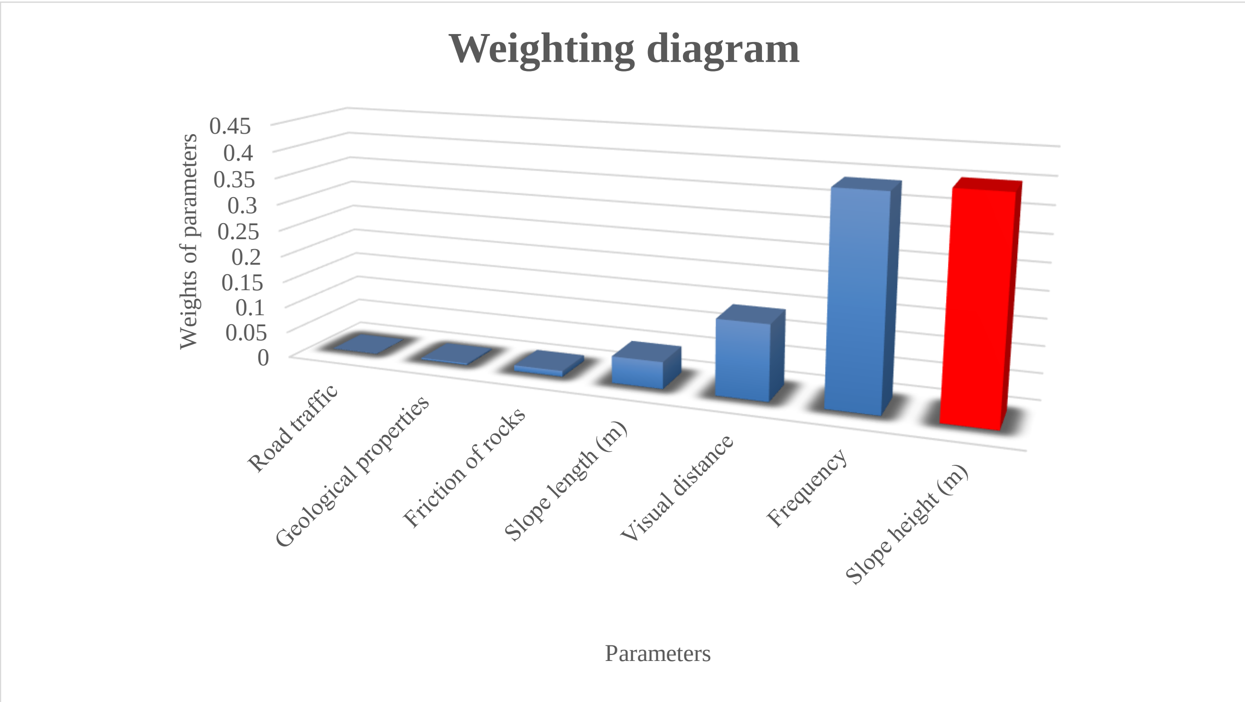

Figure 2. Risk factor weights diagram

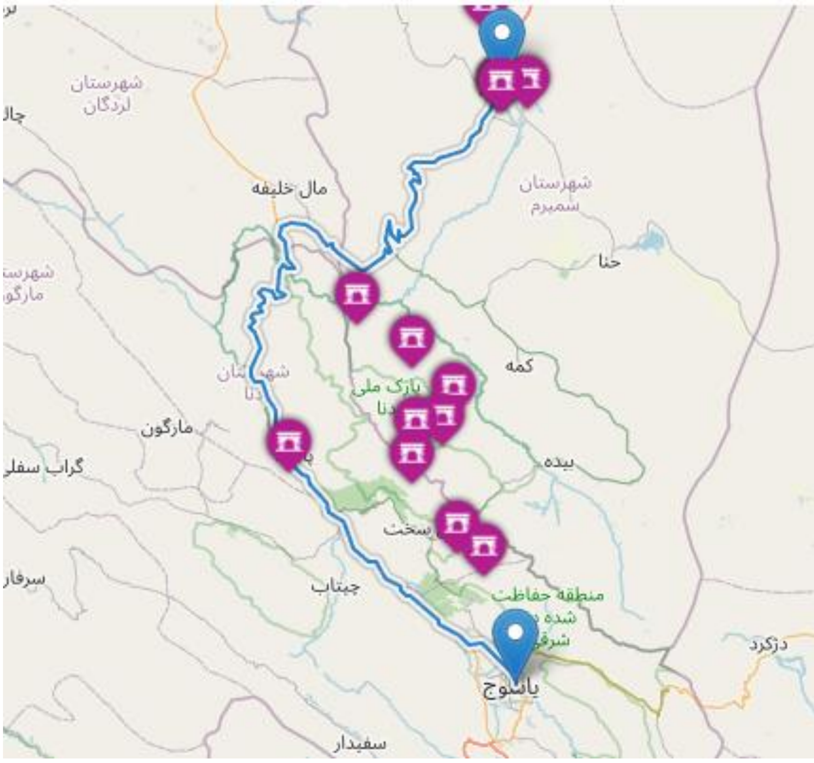

Figure 3. Yasuj - Semirom road

5. Rock Fall Risk Prioritization on Yasuj - Semirom Road

The case study of the presented model is one of the most important roads between the city of Yasuj (Kohgiluyeh and Boyer-Ahmad province) and Semirom in northeastern region of state with high trip demand due to the numerous rate of travels to Isfahan, which is guided through this route. The road is a mountainous road and therefore, so many slope falls and avalanches which ended up in road closure has occurred in years. Figure 3 demonstrates a view of this road.

Checking related data show that some segments along the road were exposed to Rock fall before and some are highly risk-prone, which are located on different parts of the path.

Eventually, 9 segments identified as mentioned in table 2. The segments were chosen based on historical records and field inspections.

By utilizing the weighted factors, the next step will be prioritizing the segments by MABAC method due to the Rock fallrisk probability conditions. All the steps demonstrated in figure 1 performed for the segments considering criteria of various indexes such as hillside slope, slope length, frequency of occurrence, and road traffic. Table 3 shows the ranking matrix of the segments due to the abovementioned weighted criteria using MABAC method and figure 4 demonstrates the distance of each alternative to BBA value, what is the key aspect of prioritizing method. It must be noted that the negative values sown in table 3 indicate that the factors have the counter effect compared to what is expected, so it is shown with a negative index that indicate the equivalent contrary side. As mentioned previously, MABAC method utilizes the distance between alternatives and the value of border approximation area. In this regard, station 2 in negative area, and stations 5 and 7 in positive area have the longest distance with BBA value. Simultaneously effects of all the criterion could be highly noted in stations number 5 and 7, which are the firsts in positive area. On the contrary, Stations number 6 and 9 are at the lowest points of the table, what means the smallest significant effect of criterion is observed and calculated in this stations, and has the least action priorities.

Table 2. Slope Fall-prone segments of Yasuj-Semirom road

NO.	Slope fall-prone segments (kilometer)
1	52.00-53.50
2	58.50-59.70
3	64.20-66.00
4	69.40-70.90
5	75.60-77.10
6	81.40-81.70
7	86.00-86.60
8	90.20-91.00
9	95.00-96.20

Table 3. Criteria matrix for ranking slope fall-prone segments

Station No	Frequency	Sight distance	Road traffic	Friction of rocks	Geological properties	Slope length (m)	Slope height (m)	Distance	Rank
1	-0.0382	0.0512	0.0004	-0.0033	-0.0008	-0.0184	-0.0268	-0.0359	6
2	-0.0622	-0.0816	0.0002	0.0022	-0.0008	0.0170	-0.0579	-0.1830	9
3	-0.0442	0.0612	0.0001	0.0078	0.0008	0.0170	-0.0470	-0.0043	5
4	0.1296	0.0112	0.0001	-0.0005	0.0008	0.0327	-0.0276	0.1464	3
5	-0.0562	-0.0745	-0.0001	0.0022	0.0008	0.0327	0.3390	0.2441	2
6	-0.0442	0.0041	-0.0001	-0.0033	-0.0008	-0.0106	-0.0237	-0.0785	8
7	0.3273	-0.0002	-0.0002	-0.0005	-0.0008	-0.0184	-0.0470	0.2602	1
8	-0.0622	0.0369	-0.0002	0.0022	-0.0008	-0.0106	0.0573	0.0228	4
9	-0.0322	0.0469	-0.0002	-0.0033	0.0024	-0.0161	-0.0626	-0.0650	7

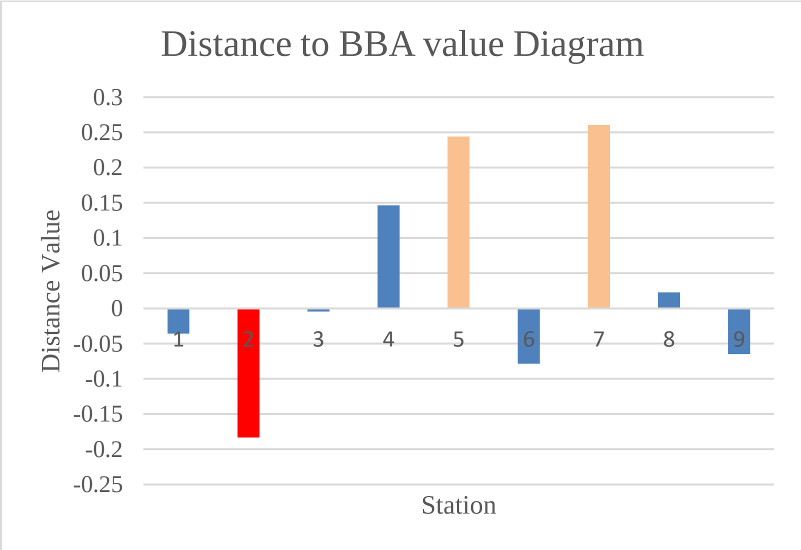

Figure 4. Distance to BBA value Diagram

6. Conclusion and Suggestions

The main goal of this study is to provide a method for Rock fall risk ranking in mountainous roads. First, principal criteria are identified considered to literature, Rock fall characteristics, and negotiating similar phenomenon. Next, criteria were weighted and prioritized by utilizing MABAC on case study of Yasuj - Semirom road. The results are listed as following:

- The most important parameter in Yasuj – Semirom Rock fall risk is slope height, what is defined as the vertical distance from the base of the slope to the crest of the slope.
- The next significant factors are the frequency of slope falls in past and the sight distance in the area.
- Considering effectiveness of road traffic in costs and casualties, this parameter is ranked as the last important factor.
- Rock fall risk rises in middle segments of the road, what means more consideration is required.
- Considering budget limit, 75.60-77.10 and 86.00-86.60 segments are ranked for the most prior segments in case of action.
- The suggested mathematical method is useable for all mountainous roads, regarded to environmental conditions and the frequency of phenomenon in the past.
- Safety actions could be applied on more dangerous segments. Hence, costs and casualties are reduced considering budget limitations during the years of action.
- Segments with more historical records of Rock fall occurrence are approximately placed in higher ranks.
- The proposed solution can be considered as a practical method and is capable of being simulated and utilized for other mountainous roads.

Suggestions for further studies are as followings:

- Providing a prioritization method of Rock fall segments using other approaches such as Electre.
- The comparative evaluation of the Mabac method and its sensitivity analysis compared to other multi-criteria models is proposed as a further research
- Providing an aggregated method considering all kinds of landslides and other mountain road incidents.
- Adding other professional parameters such as stone friction, hillside texture, and structural conditions to the factor and study.

- Introducing slope fall-prevention safety actions considering for each segment's risk level due to different environmental conditions.

7. References

– Smith, Keith, 2013. Environmental hazards: assessing risk and reducing disaster. Routledge.

– Burns, A. J. 2006. PIARC MOVES UP A GEAR. Proceedings of the ICE-Transport, 117(4), 314-315.

– Grêt-Regamey, Adrienne, and Daniel Straub.2006 "Spatially explicit avalanche risk assessment linking Bayesian networks to a GIS." Natural Hazards and Earth System Sciences 6, no. 6: 911-926.

– Vybiral, V., I. V. Kuznecov, and M. K. Osykin.1995 "Method of Pulsed Electromagnetic Emissions (PEE)-Mapping of Slope Failures in the Carpathian Mts." 57th EAGE Conference and Exhibition. European Association of Geoscientists & Engineers.

– Dung, H., Do,D. & Nguyen,V.(2022).Comparison of Multi-Criteria Decision Making Methods Using The Same Data Standardization Method. Strojnícky časopis - Journal of Mechanical Engineering, 72(2) 57-72.

– Baghsorkhi, A. R., Motamedvaziri, B., Samani, A. N., Ahmadi, H., & Moeini, A. (2022). Snow avalanche risk management in Shemshak region: a modelling, mapping and evaluation of factors affecting the occurrence of snow avalanches. CURRENT SCIENCE, 122(6), 717.

– Jamieson, Bruce, and Chris Stethem.2002 "Snow avalanche hazards and management in Canada: challenges and progress." Natural Hazards 26.1: 35-53.

– Cappabianca, F., M. Barbolini, and L. Natale.2008 "Snow avalanche risk assessment and mapping: A new method based on a combination of statistical analysis, avalanche dynamics simulation and empirically-based vulnerability relations integrated in a GIS platform." Cold Regions Science and Technology 54.3: 193-205.

– Baghsorkhi, A. R., Motamedvaziri, B., Samani, A. N., Ahmadi, H., & Moeini, A. (2022). Snow avalanche risk management in Shemshak region: a modelling, mapping and evaluation of factors affecting the occurrence of snow avalanches. CURRENT SCIENCE, 122(6), 717.

– Durlević, U., Valjarević, A., Novković, I., Ćurčić, N. B., Smiljić, M., Morar, C. & Lukić, T. (2022). GIS-based spatial modeling of snow avalanches using analytic Hierarchy process. A case study of the Šar Mountains, Serbia. Atmosphere, 13(8), 1229.

– Yariyan, P., Omidvar, E., Karami, M., Cerdà, A., Pham, Q. B., & Tiefenbacher, J. P. (2022). Evaluating novel hybrid models based on GIS for snow avalanche susceptibility mapping: A comparative study. Cold Regions Science and Technology, 194, 103453.

– Anelli, D., Tajani, F., & Ranieri, R. (2022). Urban resilience against natural disasters: Mapping the risk with an innovative indicators-based assessment approach. Journal of Cleaner Production, 371, 133496.

– Singh, V., Thakur, P. K., Garg, V., & Aggarwal, S. P. (2018). Assessment of Snow Avalanche Susceptibility of Road Network-A Case Study of Alaknanda Basin. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences.

– Pandey, A. C., Bhattacharjee, S., Salim, M., & Dwivedi, C. S. Modeling Avalanche Susceptible Zones across the Indo-China Border around the Galwan Valley, Ladakh (India): Geoinformatics-based Perspective in a High-Altitude Battlefield. In Handbook of Himalayan Ecosystems and Sustainability, Volume 2 (pp. 53-68). CRC Press.

– Zischg, A., Fuchs, S., Keiler, M., & Meißl, G. 2005. Modelling the system behaviour of wet snow avalanches using an expert system approach for risk management on high alpine traffic roads. Natural Hazards and Earth System Science, 5(6), 821-832.

– Rheinberger, Christoph M., Michael Bründl, and Jakob Rhyner.2009 "Dealing with the white death: Avalanche risk management for traffic routes." Risk Analysis: An International Journal 29.1: 76-94.

– Ahmed, Mohamed, et al. 2011 "Exploring a Bayesian hierarchical approach for developing safety performance functions for a mountainous freeway." Accident Analysis & Prevention 43.4: 1581-1589.

– Kristensen, Krister, Carl Bonnevie Kristensen, and Alf Harbitz.2003 "Road traffic and avalanches–methods for risk evaluation and risk management." Surveys in Geophysics 24.5: 603-616.

– Foster, Harold D. 2012 Disaster planning: The preservation of life and property. Springer Science & Business Media.

– Ganapathy, G. P., K. Mahendran, and S. K. Sekar.2010 "Need and urgency of landslide risk planning for Nilgiri District, Tamil Nadu State, India." International Journal of Geomatics and Geosciences 1.1: 29.

– Andrianopoulos, A., H. Saroglou, and G. Tsiambaos. 2013 "Rockfall hazard and risk assessment of road slopes." Bulletin of the Geological Society of Greece 47.4: 1664-1673.

– Akay, H. (2021). Spatial modeling of snow avalanche susceptibility using hybrid and ensemble machine learning techniques. Catena, 206, 105524.

– Straub, Daniel, and Matthias Schubert.2008 "Modeling and managing uncertainties in rock-fall hazards." Georisk 2.1 1-15.

– Mignelli, Claudia, et al.2014 "Analysis of rockfall risk on mountainside roads: evaluation of the effect of protection devices." Natural hazards 73.1 23-35.

– Yu, Shuai, Yuanhua Jia, and Dongye Sun.2019 "Identifying factors that influence the patterns of road crashes using association rules: a case study from Wisconsin, United States." Sustainability 11.7.

– [Reason, James, et al.1990 "Errors and violations on the roads: a real distinction?" Ergonomics 33.10-11:1315-1332.

– Stanojević, Predrag, Timo Lajunen, Dragan Jovanović, Paul Sârbescu, and Svilen Kostadinov. 2018 "The driver behaviour questionnaire in south-east europe countries: Bulgaria, romania and serbia." Transportation research part F: traffic psychology and behaviour 53: 24-33.

– Rivera Trujillo, C., and A. Mendoza Díaz.2009 "Análisis costo-beneficio y costo-efectividad de las medidas de seguridad implementadas en carreteras mexicanas." PUBLICACION TECNICA 319.

– Nadimi, N., NaserAlavi, S. S., & Asadamraji, M. (2022, December). Calculating dynamic thresholds for critical time to collision as a safety measure. In Proceedings of the Institution of Civil Engineers-Transport (Vol. 175, No. 7, pp. 403-412). Thomas Telford Ltd.

– Nadimi, N., Monsourifar, F., Asadamraji, M., & Amiri, A. M. (2022). Evaluation of the Impact of Covid-19 PanDemic on Transportation: a Case Study of Iran. Archives of Transport, 62.

– Justo-Silva, Rita, and Adelino Ferreira. 2019. "Pavement maintenance considering traffic accident costs." International Journal of Pavement Research and Technology 12.6: 562-573.

– Miaou, Shaw-Pin, and Harry Lum. 1993."Modeling vehicle accidents and highway geometric design relationships." Accident Analysis & Prevention 25.6: 689-709.

– Milton, John, and Fred Mannering. 1998. "The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies."

– Transportation 25.4: 395-413.

– Vayalamkuzhi, Praveen, and Veeraragavan Amirthalingam. 2016 "Influence of geometric design characteristics on safety under heterogeneous traffic flow." Journal of traffic and transportation engineering (English edition) 3.6 559-570.

– Nadimi, N., Zayandehroodi, M. A., Rahmani, F., Asadamraji, M., & Litman, T. (2023, March). Evaluation of the impact of Covid-19 on transport sustainability in Iran. In Proceedings of the Institution of Civil Engineers-Engineering Sustainability (Vol. 40, No. XXXX, pp. 1-25). Thomas Telford Ltd.

– Gooch, Jeffrey P., Vikash V. Gayah, and Eric T. Donnell.2016 "Quantifying the safety effects of horizontal curves on two-way, two-lane rural roads." Accident Analysis & Prevention 92 71-81.

– M. Li and C. Wu, “A distance model of intuitionistic fuzzy cross entropy to solve preference problem on alternatives,” Mathematical Problems in Engineering, vol. 2016, Article ID 8324124, 2016.

– Sheikholeslami, S., Boroujerdian, A. M., & Asadamraji, M. (2020). A rural road accident probability model based on single-vehicle hazard properties including hazard color and mobility: a driving simulator study. Journal of advanced transportation, 2020, 1-8.

– S.-M. Chen, S.-H. Cheng, and T.-C. Lan, “Multicriteria decision making based on the TOPSIS method and similarity measures between intuitionistic fuzzy values,” Information Sciences, vol. 367-368, pp. 279–295, 2016.

– Asadamraji, M. (2022). Novel Index of Budget Allocation to Practical Projects of Intelligent Transportation Systems in a Transit Corridor. International Journal of Transportation Engineering, 9(3), 735-747.

– M. S. Khan and Q. M. D. Lohani, “A similarity measure for Atanassov intuitionistic fuzzy sets and its application to clustering,” in Proceedings of the 2016 International Workshop on Computational Intelligence (IWCI), Dhaka, Bangladesh, December 2016.

– Asadamraji, M., Ross, V., & Yarahmadi, A. (2022). A novel hazard avoidance model based on young drivers’ characteristics: A driving simulator study. Applied Neuropsychology: Adult, 1-11.

– Lubis, A. H., Dewi, S., & Rahman, F. (2022). An Investment Selection in Transportation Subsector Using Mabac Method. INFOKUM, 10(5), 468-475.

– Wu, R. M., Zhang, Z., Yan, W., Fan, J., Gou, J., Liu, B., & Wang, Y. (2022). A comparative analysis of the principal component analysis and entropy weight methods to establish the indexing measurement. PloS one, 17(1), e0262261.