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Research Paper

Identifying the factors affecting road accidents and providing multi-criteria hybrid decision-making methods for ranking hazardous points

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Abstract

Traffic accidents and their consequences are among the major issues that need to be seriously addressed in today's world. In this study, the prioritization of hazardous points on the roads is discussed, using multi-criteria decision-making (MCDM) techniques considering different natural and environmental criteria affecting road accidents. The Neyshabour-Sabzevar and vice versa road axes in Khorasan province, Iran, are considered as a case study for the implementation of the proposed method. Initially, 20 criteria were identified in 4 different categories to prioritize the hazardous points using the literature review and the experts' opinion. In this paper, the MDL (Modified Digital Logic) and AHP (Analytical Hierarchy Process) methods are used to determine the criteria's weights. By combining these techniques, four hybrid methods MDL-TOPSIS (Technique for order preference by similarity to an ideal solution), MDL-VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje), AHP-TOPSIS, and AHP-VIKOR are obtained to prioritize the mentioned points, each producing different results. Two models were used to obtain the final ranking. In the first model, the results of these four methods are integrated using the COPELAND method. In the second model, the entropy method (Emerging Network To Reduce Orwellian Potency Yield) is used to modify the weight of the criteria. The innovation of the paper is presenting a new hybrid MCDM method that is used to prioritize hazardous points. Results showed that using the entropy method for modifying the weight of the criteria causes the methods to produce the same results. Moreover, results show that the number of deadly injured casualty of an accident is the most important criterion. Additionally, Zafaranieh residential area gained the highest priority.

Keywords: Hazardous Points, MCDM, ENTROPY Method, Copeland Method, Hybrid ranking method

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1. Introduction

Transport and communication are one of the underlying sectors in the economy of any country and are considered as an indicator of countries' development. Traffic accidents are the undesirable and unavoidable consequences of the transportation system, which cause the loss of lives, and physical and psychological injuries. Traffic engineers and police experts know that accidents usually occur at certain points, called black spots or hazardous spots. Modifying or removing these points significantly affects safety enhancement, alleviate traffic accidents and consequently, reducing injuries and wastage. Given the scarcity of funds to make safe all accident-prone areas, the identification and prioritization of these points has been of particular importance to officials and planners for eliminating incident factors. According to past studies, the identification and prioritization methods used for hazardous points have been mainly based on single-criteria methods. Some of the existing independent prioritization criteria are accident rate, number-rate of accidents, accident severity, number-severity of accidents, frequency of accident and demographic indicators. In some other studies, economic features were considered, such as first-year return rates, present net value, cost-benefit ratio, and internal rate of return (Shafabakhsh, Fathi, & Zayerzadeh, 2010). In this paper, we intend to prioritize the hazardous points using 20 criteria in four different categories. Hence, Multi-criteria decision-making (MCDM) techniques are used to rank incident points. In, MCDM multiple alternatives are prioritized considering several criteria the importance of which may vary. Different techniques have been proposed to solve MCDM problems so far.

In this paper, two commonly-used MCDM methods, namely TOPSIS and VIKOR, are used for ranking. In either of these two methods, the weight of the criteria must be specified as input. By changing the weight of the criteria, the methods produce different results. In this paper, the MDL and AHP methods are used to calculate the weights. By combining these techniques, four hybrid methods, namely MDL-TOPSIS, MDL-VIKOR, AHP-TOPSIS and AHP-VIKOR, are obtained to rank the hazardous points. The output of methods may vary.

Two models are used to integrate the results. In the first model, using the COPELAND method, the results of the four methods are integrated. In the second model, the criteria weights obtained by the AHP and MDL methods are modified using the entropy method (ENTROPY). Eventually, the results obtained from the two models are compared and analyzed. The Neyshabour-Sabzevar and vice versa road axes in Khorasan province, Iran, are considered as a case study to implement the proposed method.

The main question of this research is as follows:

- What are the ranks of hazardous points in Neyshabour-Sabzevar and vice versa road axes considering the two proposed models?
- The sub-questions of this research are listed in the following:
- What are the important criteria in ranking hazardous points?
- What is the importance of each criterion?
- What are the hazardous accident points as alternatives prioritization?
- What is the status of each alternative according to each criterion?
- How are the alternatives ranked using each combined approach?

In Section 2, a literature review is presented regarding the prioritization of hazardous points. In section 3, the research methodology is presented. In section 4, the results of implementing the research methodology steps are presented. In section 5, the results are discussed and analyzed. Eventually, conclusions and suggestions for future research are presented in the final section.

2. Literature Review

In this section, the theoretical foundations of the research are briefly discussed and then the research gap is examined.

2.1. Theoretical foundations of research

In this research, six different MCDM techniques, namely AHP, MDL, ENTROPY, TOPSIS, VIKOR, and COPELAND, are considered.

2.1.1. MDL

The MDL method is a multi-criteria decision-making method, in which the pairwise comparisons matrix is used to compare criteria and determine their importance(Dehghan-Manshadi, Mahmudi, Abedian, & Mahmudi, 2007). In this method, three values are used for comparing the elements with each other. The least important element is indicated by number (1) and the most important by number (3). For elements of equal importance, number (2) is also considered. After conducting all pairwise comparisons, the final weight of each element can be calculated by equation 1 (Beheshtinia & Nemati-Abozar, 2017).

$$W_j = \frac{\sum_{k=1}^{n} C_{jk}}{\sum_{j=1}^{n}\sum_{k=1}^{n} C_{jk}} \text{ , } j \text{ and } k = \{1,2,\dots,n\} \text{ and } j \neq k \quad (1)$$

where n is the number of criteria and W_j is the weight of criterion j. Also, if the two criteria k and j are equally important, then $C_{kj} = C_{jk} = 2$, otherwise, if criterion k is more important than criterion j, then: $C_{jk} = 1$ and $C_{kj} = 3$ and if criterion j More important than k criterion, then: $C_{jk} = 3$ and $C_{kj} = 1$.

2.1.2. AHP

The Analytical Hierarchy Process (AHP) is one of the most popular multi-criteria decision-making techniques, in which the pairwise comparison matrix is used to weight criteria and rank alternatives. In this study, the AHP method is used to determine the weight of the criteria. The AHP method can be summarized in 3 steps (Beheshtinia & Omidi, 2017):

Step 1: form the pairwise comparison matrix, named $A_{n\times n}$, where n is the number of criteria. The superiority of criterion i over criterion j (a_{ji}) is obtained by the options shown in Table 1. In this case: $a_{ji} = 1/a_{ij}$.

Step 2: Calculate the normalized value of each element (n_{ij}) of the pairwise comparisons matrix using the following equation:

$$n_{ij} = a_{ij}/\sum_{i=1}^{n} a_{ij} \quad , j = 1,2,\dots,n \quad (2)$$

Step 3: Calculate the final weight of each criterion using the following equation:

$$w_i = \sum_{i=1}^{n} n_{ij}/n \quad , j = 1,2,\dots,n \quad (3)$$

2.1.3. ENTROPY

Entropy is a multi-criteria decision-making method for calculating the weight of criteria. This method requires a decision matrix (score of each alternative with respect to each criterion). The primary idea of this method is that the higher the dispersion in the values of a criterion, the more important the criterion is. Suppose the decision matrix with n criteria and m alternatives given below, where, $A_1,A_2,\dots,A_m$ are the possible alternatives (hazardous points), $C_1,C_2,\dots,C_n$ are the criteria, and d_{ij} is the score of the alternative A_i with respect to criterion C_j.

$$S = [d_{ij}]_{m*n} = \begin{array}{c} \\ A_1 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & \dots & C_n \end{array} \\ \begin{bmatrix} d_{11} & \dots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \end{array} \quad (4)$$

In summary, the following steps are taken to obtain the criteria's weights in the entropy method:

Step 1: Calculate P_{ij} (Normalization)

$$P_{ij} = \frac{d_{ij}}{\sum_{i=1}^{m} d_{ij}} \ , \forall j \quad (5)$$

Step 2: Calculate the entropy value E_j

$$\forall j \ E_j = -k \sum_{i=1}^{m} [P_{ij} \ln P_{ij}] \ , \ k = \frac{1}{\ln m} \quad (6)$$

Step 3: Calculate the uncertainty

$$U_j = 1 - E_j \ , \forall j \quad (7)$$

Step 4: Calculate Weights w_j

$$w_j = \frac{U_j}{\sum_{j=1}^{n} U_j} \ , \ \forall j \quad (8)$$

Step 5: Calculate the adjusted weights $w_j^{'}$

$$w_j^{'} = \frac{\lambda_j w_j}{\sum_{j=1}^{n} \lambda_j w_j} \ , \forall j \quad (9)$$

The parameter k in step 2 is a constant that holds the value of Ej between 0 and 1. λ_j is a predefined weight that determined by the decision-maker. In this study, this weight is calculated once by the MDL method and once by the AHP method. The higher the difference in the alternatives' score with respect to a criterion, the lower the E_j value, resulting in a higher U_j value and higher weight for that criterion. In other words, the criteria in which alternatives' scattering is high gain more weight.

2.1.4. TOPSIS

The TOPSIS method is a multi-criteria decision-making method, in which the alternatives are ranked using the total distance of an alternative from the positive ideal point (positive ideal solution) and the negative ideal point (negative ideal solution).

In general, the following steps are taken to rank the alternatives using the TOPSIS method (Sedady & Beheshtinia, 2019).

Step 1: Consider the decision matrix (score of m alternative with respect to n criteria) with the structure shown in equation (4). Also, consider the weight of the criteria used to evaluate the alternatives ($w = [w_1, w_2, \dots, w_n]$) as input, where W_j is the weight of criterion C_j.

Step 2: Transform the decision matrix into a non-scalar or normalized (N) matrix with the following equation called the Euclidean norm.

$$nij = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}} \quad (10)$$

Step 3: Based on the following equation, the normalized weighted matrix is calculated by the obtained weights by normalized matrix's elements.

$$V = \begin{bmatrix} V11 & \dots & V1j & \dots & V1n \\ \vdots & & \vdots & & \vdots \\ Vm1 & \dots & Vmj & \dots & Vmn \end{bmatrix} \quad (11)$$

Step 4: Calculate the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS) using the following equations.

$$PIS = \{pis_1, pis_2, \dots, pis_j, \dots, pis_n\} = \{(\max v_{ij} \mid j \in J_1), (min\ v_{ij} \mid j \in J_2), i = 1, \dots, m\} \quad (12)$$

$$NIS = \{nis_1, nis_2, \dots, nis_j, \dots, nis_n\} = \{(min v_{ij} \mid j \in J_1), (\max v_{ij} \mid j \in J_2), i = 1, \dots, m\} \quad (13)$$

In these equations, V_{ij} are the elements of the weighted matrix, J_1 is the set of positive criteria, and J_2 is the set of negative criteria. In other words, for the negative criteria, in order to calculate the positive ideal solution and the negative ideal solution, the minimum and maximum values are considered, and for the positive criteria, the maximum and minimum values are considered for the positive ideal solution and the negative ideal solution.

Step 5: For each decision-making matrix, calculate the total distance of *i*th alternative from the positive ideal alternative ($DISP_i$) and the negative ideal alternative ($DISN_i$) using the following equations.

$$DISP_i = \sqrt{\left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+}\right)^2\right\}} ; i = 1,2, \dots, n \quad (14)$$

$$DISN_i = \sqrt{\left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-}\right)^2\right\}} ; i = 1,2, \dots, n \quad (15)$$

Step 6: in the final step, calculate the relative closeness index for each alternative based on the following equation and rank the alternatives (hazardous points).

$$C_i^* = \frac{DISN_i}{(DISP_i + DISN_i)};\ 0 \leq C_i^* \leq 1;\ i = 1,2,\dots,n \quad (16)$$

The alternative that has the highest relative closeness index is the best alternative and the closest to the ideal solution (its accident rate is the least of all alternatives and is the last priority for correction). Hence, according to this index, the alternatives are ranked.

2.1.5. VIKOR

The VIKOR method is another multi-criteria decision-making technique that besides considering the relative distance of alternatives from the positive ideal point in the ranking of alternatives, it also considers the parameter of the maximum distance from the positive ideal alternative in each criterion (regret index). The steps of the VIKOR method in a multi-criteria decision problem with n criteria and m alternatives are as follows (Sedady & Beheshtinia, 2019):

Step 1: Consider the decision matrix (score of m alternative with respect to n criteria) with the structure shown in equation (4). Also, consider the weight of the criteria used to evaluate the alternatives ($w = [w_1, w_2, \dots, w_n]$) as input, where W_j is the weight of criterion C_j.

Step 2: Normalize the decision matrix according to the following equation:

$$n_{ij} = d_{ij} / \sum_{i=1}^{m} d_{ij} \quad (17)$$

Step 3: Determine the positive ideal and negative ideal points. For each criterion, determine the best and worst of alternatives and name them PIS and NIS, respectively. It is assumed that the type of f_j is profit.

$$PIS = \{pis_1, pis_2, \dots, pis_j, \dots, pis_n\} = \{(\max n_{ij} \mid j \in J_1), (\min n_{ij} \mid j \in J_2), i = 1, \dots, m\} \quad (18)$$

$$NIS = \{nis_1, nis_2, \dots, nis_j, \dots, nis_n\} = \{(\min v_{ij} \mid j \in J_1), (\max v_{ij} \mid j \in J_2), i = 1, \dots, m\} \quad (19)$$

where J_1 is the set of positive criteria and J_2 is the set of negative criteria .

Step 4: Calculate the values of utility (S) and regret (R) for each alternative using the following equations:

$$S_i = \sum_{j=1}^{n} w_j \times \frac{PIS_j - n_{ij}}{PIS_j - NIS_j} \quad (20)$$

$$R_i = \max\left\{w_j \times \frac{PIS_j - n_{ij}}{PIS_j - NIS_j}\right\} \quad (21)$$

where S_i represents the relative distance of *i*th alternative from the positive ideal solution (best combination) and R_i denotes the maximum distance of *i*th alternative from the positive ideal solution for each criterion.

Step 5: Calculate the VIKOR Index (Q) for each alternative using the following equation:

$$Q_i = \begin{cases} \left[\frac{R_i - R^*}{R^- - R^*}\right] & if\ S^* = S^- \\ \left[\frac{S_i - S^*}{S^- - S^*}\right] & if\ R^* = R^- \\ \left[\frac{S_i - S^*}{S^- - S^*}\right] v + (1 - v)\left[\frac{R_i - R^*}{R^- - R^*}\right] & otherwise \end{cases} \quad (22)$$

Where: $R^* = \min R_i$, $R^- = max\ R_i$, $S^* = \min S_i$ and $S^- = max\ S_i$.

v is introduced as weight of the approach of 'the majority of attributes'. Usually, the value of v is taken as 0.5. However, v can take any value from 0 to 1(Gangil & Pardhan, 2018).

Step 6: Sort the alternatives according to S, R and Q values

The lower the value of Q, the more desirable the corresponding alternative.

2.1.6. COPELAND

After ranking the alternatives using the mentioned methods, the results should be combined. There is no specific norm to determine which approach is right. In the Copeland method, a pairwise comparison matrix is used to record the number of wins or losses of one alternative over other alternatives. The steps of this method are:

Step 1: form a table whose rows are the rank or the preference of each alternative and its columns are the methods.

Step 2: Forming the matrix of pairwise comparisons. This matrix is obtained by comparing the number of wins or losses of one alternative over another in different methods. If the number of preferences of one alternative over another is greater than the number of defeats of that alternative, then M (win) is placed in the pairwise comparison matrix, and if there is no majority vote in this comparison or the votes are equal, X (lose) will be placed in the pairwise comparison matrix.

Step 3: Add the wins column to the last column and the losses row to the last row of the pairwise comparison matrix.

Step 4: Subtract the number of losses from the number of wins to calculate the score for each alternative.

Step 5: Obtain the final rank of each alternative by sorting the numbers derived from the difference of wins and losses in descending order.

2.2. Research gap

Many studies have been conducted to prioritize the hazardous points of the roads. Geurts et al. (2004) investigated the effect of selecting appropriate weights on identification, black spot ranking, and traffic safety measures by assigning 3 different weight combinations for injury severity. In another study, Geurts et al. (2006) determined accident-prone locations by assigning weights to three types of minor, serious, and fatal injuries over a 3-year period and ranked the hazardous points by analyzing the impact severity sensitivity. Elvik (2008) compared five techniques for identifying hazardous road locations in Norway. The five techniques were compared: recording the number of accidents during a specific period, observing the accident rate (accidents per million vehicle kilometers) during a specific period, combining a critical count of accidents and an accident rate above normal during a specific period, using the empirical Bayes estimate of the expected number of accidents at each location, and determining the size of the contribution of presumably local risk factors. Montella (2010) pointed the importance of identifying black spots and their impact on safety and compared seven HotSpots IDentification (HSID) methods, considering 4 criteria. The seven methods included: 1- Accident Frequency, 2- Equal Accident Frequency Damage, 3- Rate Accidents, 4- Ratio method, 5- Experimental Bayes estimation for total crash frequency, 6- Experimental Bayes estimation for crash severity frequency, and 7- Ability to improve. Reshma and Sharif (2012), utilized a Geographic Information System (GIS) to identify some hazardous areas in south Bangalore Karnataka and prioritized the areas using the ArcGIS 10 software. Eventually, they simulated the road in the form of a digital map in order to determine the points on the ground and then used GPS to find the latitude and longitude of the points on the ground and identify those locations on the ground. Park and Young (2012) examined the Strategic Highway Safety Plan (SHSP) and Traffic Safety Action Plan of 53 jurisdictions in North America, And they used a binomial beta test to clarify and prioritize the areas of importance.

Kwak and Kho (2016) developed real-time crash risk prediction models for different segments to control traffic flow on expressways. They investigated the effect and application of detector stations in uneven intervals in order to predict crash risk on expressways. Results showed that the traffic flow characteristics leading to crashes differ based on the segment and traffic flow. Zhang et al. (2016) analyzed the traffic accident data from 2006 to 2010 in Guangdong Province, China, using a logistic regression model in order to assess the effects of factors such as human factors, type of the vehicle, road conditions, and environmental factors on driver fatigue and the severity of the accident resulted by it. Results show that factors such as inexperienced drivers, vehicle's unsafe condition, slippery roads, night driving on illuminated streets, and weekends have no significant effect on fatigue-related accidents. However, they are likely to increase the severity of accidents. Kountouriotis and Merat (2016) examined the impact of visual and non-visual factors on drivers' distraction and analyzed this issue with respect to the geometrical condition of the road and the presence or absence of other vehicles around the driver. Results showed that a driver's distraction is strongly influenced by factors such as speed, accuracy and driving control. Farajollahi and Delavar (2017) identified the hazardous points and the potential accident locations in an area considering the factors affecting traffic accidents, such as the accident severity parameter. They determined the importance of each factor using the Expert Choice software, which is a decision analysis software based on Analytic Hierarchy Process(AHP). Dereli and Erdogan (2017) developed a descriptive model to determine the black spots of traffic accidents on roads in Turkey using model-based spatial statistical methods, namely Poisson regression, negative binomial regression, and empirical Bayesian method. The ultimate goal of this research was to develop a model that enables the evaluation of all methods in Geographic Information Systems (GIS). By comparing the methods used in this study, it was found that the experimental Bayesian method yielded the best results in terms of accuracy and consistency. Hoe et al. (2018) investigated the causes of road accidents, especially among motorcyclists in Malaysia. Results showed that road lighting and human distraction are common factors in road accidents in Malaysia. Using the AHP model, this study proposed a deep approach for analyzing environmental factors, such as climatic and road factors that lead to motorcycle accidents. Nenadić (2019) investigated the road hazardous point using a Multi-Criteria Decision Making Model (MCDM) considering five quantitative and two qualitative criteria for vehicle traffic safety. First, the criteria's weight coefficients were defined using the FUll Consistency Method (FUCOM). Then, the hazardous sections of the road were ranked using the Weighted Aggregate Sum Product Assessment (WASPAS) method. Tola and Gebissa (2019) utilized the ArcGIS software as a data analysis tool to identify the black spots of traffic accidents in the South Wollo zone, Ethiopia, on the Kombolcha-Dessie road segment. The five-year history of accidents on the Kombolcha-Dessie Road was spatially distributed on a digitized road map (including crash sites) to identify the most disaster-prone locations and their weights were applied based on the severity of the accident. As the result, five accident hotspot locations were identified. Fernandez et al. (2020) employed the Analytic Hierarchy Process (AHP) method to analyze the data and prioritize the road accident factors. The results of this study showed that a high level of understanding of traffic signs generally results in a more accurate and reliable prioritization of road accident factors. Moreover, it was found that the factor with the highest rank among road accident factors is lack of knowledge of traffic signs, while the lowest-ranked factor is bad driving behavior. Abdel-basset et al. (Abdel-Basset, Gamal, Chakrabortty, & Ryan, 2021) applied a new hybrid MCDM (AHP-PROMETHEE II) approach that is proposed for OWPS location selection. Seven criteria and their related sub-criteria are considered for such decision-making. The trapezoidal neutrosophic numbers are introduced to dispose uncertainties. A case study is carried out based on five locations in the Red Sea region of Egypt. Model's effectiveness is verified by rigorous experimentations and comparisons against different MCDM approaches. Bakioglu and Atahan (Bakioglu & Atahan, 2021) in their study addresses the prioritization of risks involved with self-driving vehicles by proposing new hybrid MCDM methods based on AHP, TOPSIS and VIKOR under Pythagorean fuzzy environment. The result of the proposed model is validated by performing sensitivity analysis. The performance of the proposed methodology with Pythagorean fuzzy sets is also compared with those with ordinary fuzzy sets and it is revealed.

that the proposed method produces reliable and informative outcomes better representing the impreciseness of decision-making problems.

Results of the literature review show that no studies in the subject literature presented a comprehensive set of criteria for identifying and prioritizing incident points and only a few types of criteria and methods have been applied. In this paper, the accident points in the Neyshabour-Sabzevar and vice versa road axes are prioritized considering 20 criteria in four different categories that influence accidents. In order to prioritize the accident points, two new models, each containing 4 new hybrid methods, have been used. In the first model, the five MDL, AHP, TOPSIS, VIKOR, and COPELAND techniques are combined and in the second model, the five techniques of MDL, AHP, TOPSIS, VIKOR, and ENTROPY are combined.

The innovations of this article are as follows:

• considering 20 criteria for hazardous and Introducing four new criteria in addition to the criteria mentioned in the literature review: 1) The road's daylight slope 2) Climate conditions 3) Access roads and U-turns, and 4) Adequate number of parking spots and welfare complexes.

• Introducing two new MCDM hybrid models using the MDL, AHP, ENTROPY, TOPSIS, VIKOR, and COPELAND techniques to rank hazardous points.

3. Research method

As mentioned before, in this paper, the hazardous points are ranked using two hybrid models of MCDM methods. The Neyshabour-Sabzevar and vice versa road axes, in Khorasan province, Iran, is considered as a case study to implement the proposed method.

The research steps are as follows:

Step 1. Identify the criteria that affect the accident points using the literature review and the experts' opinions.

Step 2. Identify potential hazardous points as alternatives

Step 3. Determine the score of each alternative with respect to each criterion

Step 4. Determine the criteria's scores using the MDL and AHP methods: the pairwise comparison matrix is used in both methods to rank the alternatives. In the MDL method's pairwise comparison matrix only the superiority or non-superiority of one criterion over the other are asked from the decision-makers, while the AHP method requires more detailed information for each comparison, including the superiority difference of one criterion over another. Therefore, it can be said that it offers a better final ranking. However, if there are a large number of criteria, the likelihood of error occurrence in completing the matrix of paired comparisons by decision-makers increases. Therefore, both methods are utilized in this study.

Step 5. Prioritize the hazardous points using the first model

As mentioned, the TOPSIS and VIKOR methods are used to rank the alternatives. In these methods, different approaches are taken to tank the alternatives. In TOPSIS, the average distance of each alternative from the ideal positive and negative ideal points are considered, while in VIKOR, the relative distance of the alternatives from the positive ideal point and the maximum distance of the alternatives from the positive ideal point are examined in each criterion (Regret Index). Hence, these two techniques may offer different ratings. In addition, the weight of the criteria should be given as input to these methods. Therefore, their result will change as these inputs change. In this research, the AHP and MDL methods may be used in the first model to calculate weights. Therefore, there are 4 combinations as described in the following:

AHP-TOPSIS: In this method, the weights of criteria are determined by the AHP method and the alternatives are ranked using the TOPSIS method.

MDL-TOPSIS: In this method, the weights of criteria are determined by the MDL method and the alternatives are ranked using the TOPSIS method.

AHP-VIKOR: In this method, weights of criteria are determined by the AHP method and the alternatives are ranked using the VIKOR method.

MDL-VIKOR: In this method, the weights of criteria are determined by the MDL method and the alternatives are ranked using the VIKOR method.

Due to the different results of each method, finally, Copeland technique is used to integrate the results of these methods.

Step 6. Prioritize the hazardous points using the second model

The second model is similar to the first model, with this difference that the combination of Entropy with the MDL and AHP methods is used to determine the criteria’s weights. Therefore, the methods used in this model are as follows:

AHP-Entropy-TOPSIS:

In this method, the criteria’s weights are determined by combining the Entropy and AHP methods and the alternatives are ranked using the TOPSIS method.

MDL-Entropy-TOPSIS: In this method, the criteria’s weights are determined by combining the Entropy and MDL methods and the alternatives are ranked using the TOPSIS method.

AHP-Entropy-VIKOR:

In this method, the criteria’s weights are determined by combining the Entropy and AHP methods and the alternatives are ranked using the VIKOR method.

MDL-Entropy-VIKOR:

In this method, the criteria’s weights are determined by combining the Entropy and MDL methods and the alternatives are ranked using the VIKOR method.

Figure 1 illustrates the conceptual model of the research methodology.

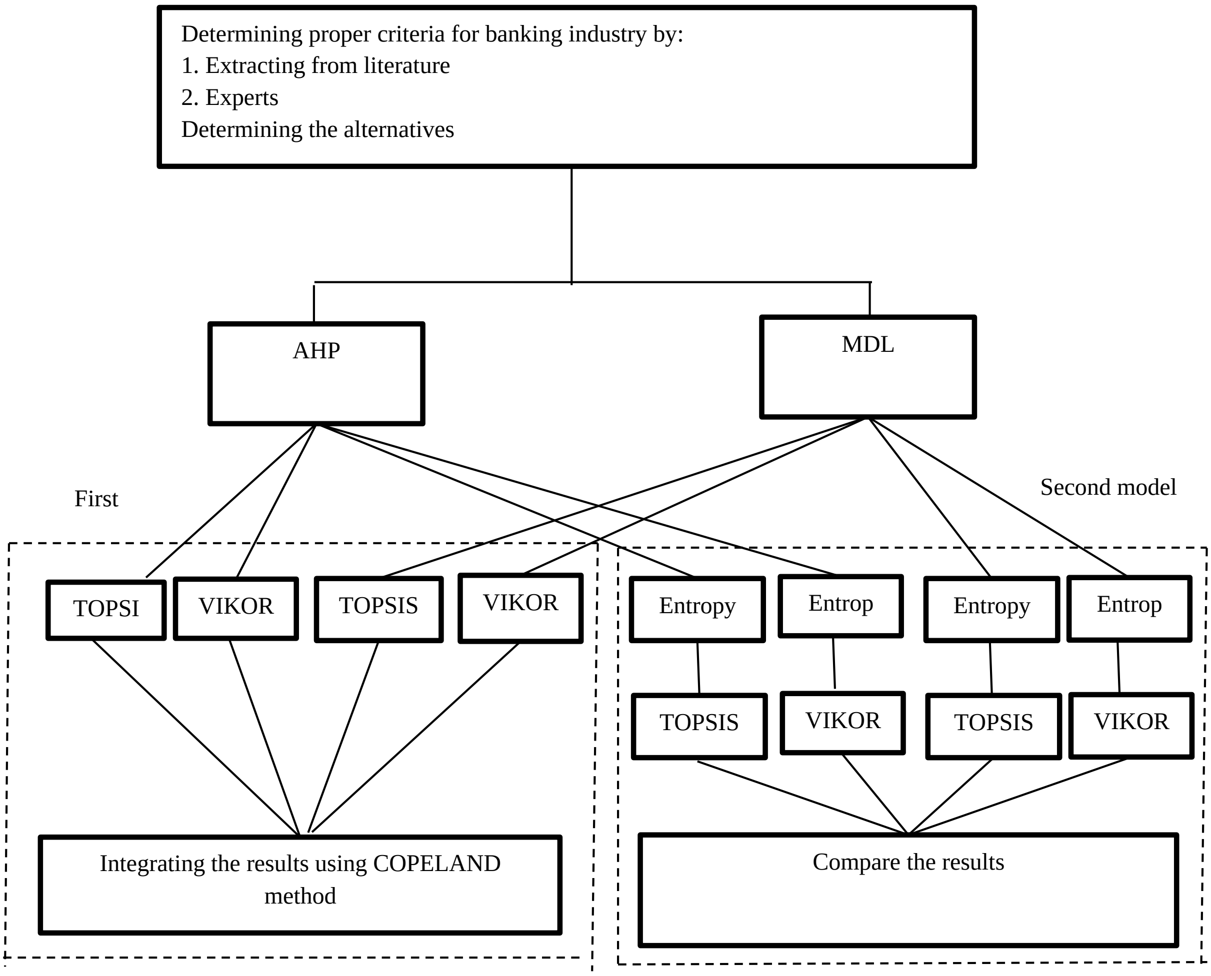

Figure 1. Conceptual model of the research methodology

Two questionnaires are used in this study. The first questionnaire is used in Step 3 for pairwise comparisons between the criteria and the second questionnaire is used in step 4 to determine the status of each alternative according to each criterion. In the first questionnaire, the decision-makers compare the two criteria with each other and rank the alternatives according to the descriptive terms shown in Table 1. In the second questionnaire, each alternative is rated with respect to each criterion. Given the qualitative nature of some criteria, the expressions in Table 1 are used to determine these scores.

The questionnaires were completed by eight experts with more than 10 years of experience, chosen from the Road Administration staff. Both questionnaires are standard and their validity is confirmed (Sedady & Beheshtinia, 2019). The reliability of the first questionnaire was confirmed by the inconsistency rate of 0.07 (less than 0.1) and the reliability of the second questionnaire was confirmed by Cronbach's alpha of 0.86 (above 0.7).

Table 1. Linguistic terms and their numerical equivalents

First Questionnaire (AHP)*		Second questionnaire (Decision Matrix)			
Comparison of superiority	Degree of importance	Symbol	Descriptive phrase	Quantitative value for positive criteria	Quantitative value for negative criteria
Equal preference	1	VP	Very poor	9	1
Moderate	3	P	Poor	7	3
Strong preference	5	M	Normal	5	5
Very strong	7	G	Well	3	7
Absolute	9	VG	Very well	1	9

*The numbers 2, 4, 6 and 8 are considered intermediate numbers.

4. Calculation results

In this section, the results obtained from implementing the research steps are presented:

4.1. Step 1: Identifying the criteria affecting the hazardous points

As noted, according to in-depth interviews with experts 20 criteria were identified in 4 categories, 16 criteria extracted from the literature and 4 obtained from the expert's opinion. These criteria are visible in Table 2. The new criteria introduced in this study are as follows:

1. The road's daylight slope: When the daylight slope is inadequate, the remaining water in the road freezes in winter, and it leads to accidents.

2. Climatic conditions: High rainfall, snow, frost, and fog on the road also make driving difficult and cause accidents.

3. Access roads and U-turns: Inadequate status of U-turns and access roads on the road can reduce road safety and cause irreversible accidents.

4. Adequate number of parking spots and welfare complexes: Inadequate number of parking and unsuitable distance between welfare complexes can also play a significant role in the fatigue and drowsiness of drivers and cause accidents

Table 2. Criteria weighting using MDL and AHP

Category	Symbol	Criterion description	Symbol	Reference	weight (MDL)	weight (AHP)
The geometric status of the road	C_1	Steep slope	C_{11}	[Sadeghi, Ayati and Pirayesh Neghab, 2013]	0.017	0.011
		Road arch status	C_{12}	[Shafabakhsh, Fathi and Zayerzadeh, 2010]	0.056	0.078
		Road's daylight slope	C_{13}	Experts	0.0482	0.047
		Road sight status	C_{14}	[Shafabakhsh et al., 2010]	0.0477	0.038
		Road width	C_{15}	[Reshma and Sharif, 2012]	0.0398	0.019
		Pavement	C_{16}	[Sadeghi et al., 2013]	0.0323	0.012
Traffic situation	C_2	Number of passing cars	C_{21}	[Reshma and Sharif, 2012]	0.072	0.033
		Combined traffic (light and heavy)	C_{22}	[Reshma and Sharif, 2012]	0.0523	0.015
		Allowed speed	C_{23}	[Sadeghi et al., 2013]	0.092	0.098
Number of accidents	C_3	Number of deaths	C_{31}	[Geurts et al., 2004]	0.132	0.213
		Number of injured in the accident	C_{32}	[Geurts et al., 2004]	0.088	0.045
		Number of minor accident (without injuries)	C_{33}	[Geurts et al., 2004]	0.044	0.019
Road safety status	C_4	Adequate horizontal and vertical signs	C_{41}	[Shafabakhsh et al., 2010]	0.039	0.061
		Road climatic condition	C_{42}	Experts	0.033	0.024
		Access roads and U-turn	C_{43}	Experts	0.035	0.029
		Adequate number of parking spots and welfare complexes Adequacy	C_{44}	Experts	0.041	0.082
		Specific locations (tunnels, bridges, road neck, foggy points, sandstorms, etc.)	C_{45}	[Shafabakhsh et al., 2010]	0.038	0.055

Category	Symbol	Criterion description	Symbol	Reference	weight (MDL)	weight (AHP)
		Lighting status (natural)	C_{46}	[Al-Masaeid, 1997]	0.034	0.036
		Lighting status (artificial)	C_{47}	[Al-Masaeid, 1997]	0.042	0.064
		Drainage status	C_{48}	[Shafabakhsh et al., 2010]	0.015	0.022

4.2. Step 2: Determine the potential incident points as alternatives

The road's accident statistics were obtained for 2016, 2017, and 2018 by referring to Khorasan Razavi Road Police Department reports. Using these reports along with in-depth interviews with experts, 7 accident points were identified, as shown in Table 3.

4.3. Step 3: Determine the score of each alternatives with respect to each criterion

By distributing the second questionnaire to the experts, a decision matrix was prepared for each expert. Table 4 shows the integrated decision matrix derived from the arithmetic mean of experts' scores.

Table 3. Characteristics of hazardous points on Neyshabour-Sabzevar axis and vice versa

Alternative	Road name	Point/Cross name	Distance from the origin of the axis (Km)
A_1	Neyshabour - Sabzevar	After Noabad U-turn	35
A_2	Neyshabour - Sabzevar	Rahim-Abad Village	5
A_3	Neyshabour - Sabzevar	Cotton-cleaning factory	15
A_4	Neyshabour - Sabzevar	Kaal-shoor Bridge	20
A_5	Sabzevar – Neyshabour	Intersection	45
A_6	Sabzevar – Neyshabour	Robat-e Sarpoosh Residential area	17
A_7	Sabzevar – Neyshabour	Zafaranieh Residential area	35

Table 4. Integrated decision matrix

Criteria / Points	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}	C_{47}	C_{48}
A1	1	2.333	7.667	7	7	8.333	424444	0.34	110	0	6	3	5	5.667	7	2	2.333	9	1.667	5
A2	1	2.333	6.333	7.667	6	8.333	424444	0.34	100	1	3	4	3	5.667	4.333	1	2.333	9	3	4
A3	1	1	7	7	7	8.333	424444	0.34	110	0	3	2	5	5.667	4.333	1	2.333	9	3	5
A4	2	5.667	7.667	5	7	5.667	424444	0.34	110	0	2	1	1	5.667	7	1	7	8	1.667	5
A5	1	1.667	7	6.333	7	7	481755	0.32	103.33	0	3	2	3	7	4.333	2	2.333	9	1.667	4
A6	1	2.333	7.667	5	7	5.667	481755	0.32	85	0	7	3	3	7	7	1	2.333	9	1.667	5
A7	1	2.333	8.333	5	6	5.667	481755	0.32	85	2	3	5	3	7	4.333	1	2.333	8	3	5

4.4. Step 4: Determine the scores of each criterion using MDL, AHP and Entropy methods

Once the criteria are identified, the questionnaires were distributed among the experts in order to determine their weights. The weight of each criterion was obtained using the MDL and AHP methods, the results of which are presented in Table 2.

4.5. Step 5: Prioritize hazardous points using the first model

The results of implementing the four methods are as follows:

4.5.1. AHP-TOPSIS

As mentioned, in this method, the criteria's weights are determined by the AHP method and the alternatives are ranked using the TOPSIS method. Regarding the weight of the criteria based on the AHP method, the normalized decision matrix is shown in Table 5. Also, table 6 shows the difference of alternatives from positive ideal points ($DISP_i$) and negative ideal points ($DISN_i$), closeness index (C_i^*) and the rank of each alternative.

Table 5. Normalized decision matrix in the AHP-TOPSIS method

Type of Criteria	max	max	max	min	min	min	max	max	max	max	max	max	min	min	min	min	max	min	min	min
Criteria / Points	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}	C_{47}	C_{48}
A1	0.003	0.024	0.018	0.016	0.007	0.005	0.012	0.006	0.04	0	0.024	0.007	0.033	0.008	0.014	0.045	0.014	0.014	0.017	0.009
A2	0.003	0.024	0.015	0.018	0.006	0.005	0.012	0.006	0.037	0.095	0.012	0.009	0.02	0.008	0.008	0.023	0.014	0.014	0.031	0.007
A3	0.003	0.01	0.017	0.016	0.007	0.005	0.012	0.006	0.04	0	0.012	0.005	0.033	0.008	0.008	0.023	0.014	0.014	0.031	0.009
A4	0.007	0.058	0.018	0.012	0.007	0.004	0.012	0.006	0.04	0	0.008	0.002	0.007	0.008	0.014	0.023	0.043	0.012	0.017	0.009
A5	0.003	0.017	0.017	0.015	0.007	0.004	0.013	0.005	0.038	0	0.012	0.005	0.02	0.01	0.008	0.045	0.014	0.014	0.017	0.007
A6	0.003	0.024	0.018	0.012	0.007	0.004	0.013	0.005	0.031	0	0.028	0.007	0.02	0.01	0.014	0.023	0.014	0.014	0.017	0.009
A7	0.003	0.024	0.02	0.012	0.006	0.004	0.013	0.005	0.031	0.191	0.012	0.012	0.02	0.01	0.008	0.023	0.014	0.012	0.031	0.009
PIS	0.007	0.058	0.02	0.012	0.006	0.004	0.013	0.006	0.04	0.191	0.028	0.012	0.007	0.008	0.008	0.023	0.043	0.012	0.017	0.007
NIS	0.003	0.01	0.015	0.018	0.007	0.005	0.012	0.005	0.031	0	0.008	0.002	0.033	0.01	0.014	0.045	0.014	0.014	0.031	0.009

Table 6. Final Prioritization using the MDL-TOPSIS and AHP-TOPSIS Methods

Hazardous Point	AHP-TOPSIS				MDL-TOPSIS			
	$DISP_i$	$DISN_i$	C_i^*	Rank	$DISP_i$	$DISN_i$	C_i^*	Rank
A_1	0.199	0.028	0.122	5	0.125	0.037	0.229	5
A_2	0.109	0.1	0.481	2	0.076	0.065	0.459	2
A_3	0.202	0.026	0.113	6	0.131	0.019	0.124	7
A_4	0.192	0.068	0.262	3	0.127	0.048	0.273	3
A_5	0.2	0.023	0.103	7	0.129	0.02	0.131	6
A_6	0.196	0.039	0.167	4	0.124	0.046	0.273	4
A_7	0.052	0.193	0.788	1	0.047	0.122	0.72	1

4.5.2. MDL-TOPSIS

All calculations of this method are similar to the previous method, except that the criteria's weights are calculated using the MDL method. The difference of alternatives from positive ideal points ($DISP_i$) and negative ideal points ($DISN_i$), closeness index (C_i^*) and the rank of each alternative are shown in Table 6.

4.5.3. AHP-VIKOR

As mentioned, in this method, the criteria's weights are determined by the AHP method and the alternatives are ranked using the TOPSIS method. Table 7 shows the normalized matrix and the positive and negative ideal points.

The S, R, and Q indices and the rank of each alternative with respect to the weight of the criteria obtained from the AHP method are shown in Table 8.

Table 7. Normalized decision matrix in the AHP-VIKOR method

Type of Criteria	max	max	max	min	min	min	max	max	max	max	max	max	min	min	min	min	max	min	min	min
Criteria / Points	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{46}	C_{47}	C_{48}
A1	0.125	0.132	0.148	0.163	0.149	0.17	0.135	0.147	0.156	0	0.222	0.15	0.217	0.13	0.183	0.222	0.111	0.148	0.106	0.152
A2	0.125	0.132	0.123	0.178	0.128	0.17	0.135	0.147	0.142	0.333	0.111	0.2	0.13	0.13	0.113	0.111	0.111	0.148	0.191	0.121
A3	0.125	0.057	0.135	0.163	0.149	0.17	0.135	0.147	0.156	0	0.111	0.1	0.217	0.13	0.113	0.111	0.111	0.148	0.191	0.152
A4	0.25	0.321	0.148	0.116	0.149	0.116	0.135	0.147	0.156	0	0.074	0.05	0.043	0.13	0.183	0.111	0.333	0.131	0.106	0.152
A5	0.125	0.094	0.135	0.147	0.149	0.143	0.153	0.138	0.147	0	0.111	0.1	0.13	0.16	0.113	0.222	0.111	0.148	0.106	0.121
A6	0.125	0.132	0.148	0.116	0.149	0.116	0.153	0.138	0.121	0	0.259	0.15	0.13	0.16	0.183	0.111	0.111	0.148	0.106	0.152
A7	0.125	0.132	0.161	0.116	0.128	0.116	0.153	0.138	0.121	0.667	0.111	0.25	0.13	0.16	0.113	0.111	0.111	0.131	0.191	0.152
PIS	0.25	0.321	0.161	0.116	0.128	0.116	0.153	0.147	0.156	0.667	0.259	0.25	0.043	0.13	0.113	0.111	0.333	0.131	0.106	0.121
NIS	0.125	0.057	0.123	0.178	0.149	0.17	0.135	0.138	0.121	0	0.074	0.05	0.217	0.16	0.183	0.222	0.111	0.148	0.191	0.152

Table 8. Calculation of S, R, and Q indices and the Prioritization in the MDL-VIKOR and AHP-VIKOR Methods

	AHP-VIKOR				MDL-VIKOR			
Hazardous points \ Index	S	R	Q	Rank	S	R	Q	Rank
A_1	0.691	0.213	0.964	6	0.627	0.132	0.885	5
A_2	0.569	0.107	0.309	2	0.575	0.072	0.289	2
A_3	0.714	0.213	1	7	0.688	0.132	1	7
A_4	0.396	0.213	0.5	3	0.442	0.132	0.542	3
A_5	0.685	0.213	0.954	5	0.655	0.132	0.937	6
A_6	0.633	0.213	0.873	4	0.586	0.132	0.809	4
A_7	0.411	0.098	0.024	1	0.419	0.092	0.167	1

4.5.4. MDL-VIKOR

All calculations of this method are similar to the previous method, except that the criteria's weights are calculated from the MDL method. The S, R and Q indices and the rank of each alternative with respect to the weight of the criteria obtained from the AHP method are shown in Table 8.

4.5.5. First model

As mentioned, each of the four methods produces a different result. In this model, the Copeland method is used to integrate the results obtained from different methods. Table 9 shows the results obtained from the Copeland method.

4.6. Step 6: Prioritizing hazardous points using the second model

4.6.1. Second model

In this model, the weights of the criteria are modified by the entropy method and then the alternatives are ranked by the VIKOR and TOPSIS methods. Tables 10 and 11 show the results of the MDL-Entropy-TOPSIS, MDL-Entropy-VIKOR, AHP-Entropy-TOPSIS, and AHP-Entropy-VIKOR combined methods.

Table 9. Final Prioritization of the First Model (Copeland Method)

Alternatives	Win	Lose	Difference	Rank
A_1	2	4	-2	5
A_2	5	1	4	2
A_3	0	6	-6	7
A_4	4	2	2	3
A_5	1	5	-4	6
A_6	3	3	0	4
A_7	6	0	6	1

Table 10. Final Prioritization using the MDL-ENTROPY-TOPSIS and AHP-ENTROPY-TOPSIS Methods

	AHP-ENTROPY-TOPSIS				MDL-ENTROPY-TOPSIS			
Hazardous points	$DISP_i$	$DISN_i$	$\overline{C_i^*}$	Rank	$DISP_i$	$DISN_i$	$\overline{C_i^*}$	Rank
A_1	0.359	0.039	0.098	5	0.277	0.067	0.195	5
A_2	0.196	0.177	0.475	2	0.164	0.139	0.46	2
A_3	0.366	0.022	0.057	7	0.29	0.022	0.072	7
A_4	0.347	0.12	0.256	3	0.276	0.103	0.272	3
A_5	0.361	0.026	0.066	6	0.285	0.027	0.087	6
A_6	0.357	0.051	0.125	4	0.275	0.082	0.23	4
A_7	0.094	0.348	0.788	1	0.098	0.268	0.733	1

Table 11. Calculation of S, R, and Q indices and the Prioritization in MDL-ENTROPY-VIKOR and AHP-ENTROPY-VIKOR Methods

	AHP-ENTROPY-VIKOR				MDL-ENTROPY-VIKOR			
Index / Hazardous points	S	R	Q	Rank	S	R	Q	Rank
A_1	0.826	0.386	0.95	5	0.731	0.294	0.854	5
A_2	0.585	0.193	0.353	2	0.603	0.147	0.263	2
A_3	0.876	0.386	1	7	0.861	0.294	1	7
A_4	0.502	0.386	0.625	3	0.569	0.294	0.673	3
A_5	0.841	0.386	0.965	6	0.813	0.294	0.946	6
A_6	0.695	0.386	0.819	4	0.61	0.294	0.719	4
A_7	0.377	0.114	0	1	0.415	0.13	0	1

As can be seen, all four methods yielded similar results.

4.7. Discussion

As noted, each MCDM approach rates criteria and alternatives according to a different perspective and may yield different results from other methods. For example, in the MDL method's pairwise comparison matrix only the superiority or non-superiority of one criterion over the other are asked from the decision-makers, while the AHP method requires more detailed information for each comparison, including the superiority difference of one criterion over another.. On the other hand, in the TOPSIS method, the difference between positive and negative ideal points are used, while in the VIKOR method, the relative distance of each alternative from the positive ideal point and the maximum distance of each alternative to the ideal positive point in each criterion are considered (regret index). The final examination of the models shows that the final result of the first model (obtained by the Copeland method) is very close to the result of each of the four models presented in the second model and they are nearly equal. This is due to the entropy adjustment of weights. The entropy method gives more weight to the criteria in which alternatives have more diverse scores. That is, if the scores of the alternatives are the same in a criterion, that criterion will not differentiate the alternatives and determine their relative superiority. In the second model, the effect of entropy weights on both AHP and MDL methods leads to convergence of the weights of the objective functions. Therefore, the similarity of the results of AHP-ENTROPY-VIKOR with MDL-ENTROPY-VIKOR and those of AHP-ENTROPY-TOSIS with MDL-ENTROPY-TOSIS is somehow justified. On the other hand, in the VIKOR method, the maximum difference between the alternatives and the positive ideal point is taken into account (regret index). The high value of this index means the high dispersion of alternatives in the particular criterion. Therefor the weight of that criterion is increased. This causes the criterion to influence the distance of the alternatives from the positive ideal point, causing the two parameters of distance to the positive ideal point and the regret index to be closer to each other and makes the results of the TOPSIS method closer to VIKOR.

The final result of both models indicate that the Zafaranieh Residential area (A7) has the highest priority and the Cotton-cleaning Factory (A3) has the lowest priority. Moreover, in the MDL method, the number of deaths, allowed speed, and the number of injured in the accident were respectively the most important, and the criteria of drainage, steep slope, and pavement were the least important. Also in the AHP method, the criteria of the number of deaths, allowed speed and adequate number of parking spots and welfare complexes are the most important, respectively.

5. Summary, Conclusions, and Field of Future Research

5.1. Summary

Accidents are considered as an important aspect of risks. Most accidents occur at certain points called black spots or accident points. Modifying or removing accident points has a significant impact on improving safety, reducing traffic accidents, reducing injuries and wastage. The experience of other countries shows that while such measures sometimes incur heavy financial costs, resolving these safety problems can reduce the number of deaths or severe injuries to many people.

In this paper, the hazardous points in the Neyshabour-Sabzevar and vice versa road axes were prioritized, taking into account the natural and physical hazards affecting road accidents, using 20 criteria affecting accidents. For this purpose, in addition to employing the criteria previously used in the literature, four new criteria were introduce, namely the road's daylight slope, climatic condition, road access and U-turns, and adequate number of parking spots and welfare complexes. Then, after identifying the hazardous points using two models, each consisting of 4 hybrid methods, the priority of the hazardous points were obtained.

5.2. Research implications

In this research, a comprehensive list of criteria for determining the priority of hazardous points was presented. These criteria can help managers to study other roads and prioritize hazardous areas. In addition, the proposed model in this study can be applied to other roads. By identifying hazardous areas, the organizations' limited funds are spent more effectively to make roads safer. From a social point of view, by prioritizing and improving incident points, the number of accidents that lead to financial loss, injury, and other associated social costs are reduced.

5.3. Suggestion for future research

The use of other multi-criteria decision-making methods for weighting the criteria may be scope for future research. Moreover, combining other multi-criteria decision-making methods to prioritize hazardous points, developing the proposed method using fuzzy-based approaches, introducing new criteria to prioritize hazardous points, and using the hybrid methods presented in this study to prioritize alternatives in other industries, can also be considered in future research. Given the changing nature of the research subject, it is suggested that similar research be conducted in the coming years. In addition, the proposed model in this study can be applied to other roads.

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