Research Article

Location of Emergency Escape Ramps on Two-Lane Rural Highways Based on the Fuzzy Multicriteria Decision-Making Method

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Today, the lack of practical research is one of the most important concerns worldwide, and location, which is an important issue in most projects, has received less attention from experts. In this study, the location criteria of emergency escape ramps were examined, and according to the Myers formula, the temperature-distance diagram along the route was obtained. Also, the speed of vehicles entering the escape ramp was examined according to the American Association of State Highway and Transportation Officials (AASHTO) in the proposed options that were obtained from the experts. Then, 3 general criteria and 16 subcriteria were classified, and finally, the importance of criteria was examined by the fuzzy analytic hierarchy process (F-AHP), and the high-priority options were illustrated using the fuzzy technique for order performance by similarity to ideal solution (F-TOPSIS). The proposed options were evaluated and prioritized for an emergency escape ramp on the two-lane rural highways of Salavat Abad village pass of Sanandaj city, Kurdistan Province, Iran. The results showed that the technical criteria with more than 69% among the general criteria and subcriteria of the percentage of longitudinal slope, longitudinal slope length, and vehicle design speed were the most important factors influencing the location of an emergency escape ramp. Moreover, among the proposed options, the four options 3, 4, 5, and 6 had the highest score, and option 6 (Kurkur turn (2)) was identified as the most priority location for implementing the emergency escape ramp.

1. Introduction

From the emergence of communication roads between cities and other communication points, users of these roads have been thinking of development and better usage of these roads in all seasons and different ways. Nowadays, over time and the implementation of the developments obtained after many years in communication roads, the vast volume of these roads, especially in Iran, where most of the densely populated and busy sections are mountainous, always have particular characteristics and are separated from the roads that exist in the plains and deserts. The installation of an emergency escape ramp can somehow be a development idea for better use of the roads in question to prevent accidents that lead to further damages [1–4]. The emergency escape ramp is a traffic device that enables vehicles with braking problems to stop safely. It is typically a long, sand- or gravel-filled lane connected to a steep downhill grade section of a main road and is designed to accommodate large trucks or buses. It allows the kinetic energy of a moving vehicle to be dissipated gradually in a controlled and relatively harmless way, helping the operator stop it safely [5, 6].

Location is a lifetime decision-making process in which a set of different information according to the goals and limitations of the project is collected and evaluated in successive stages in order to finally achieve the optimal location option, according to the goals and needs of a project. Location problems are a branch of operations research and are among the problems whose information varies depending on geographical situations [7, 8]. The main purpose of location problems is maximum success in achieving the goals of stakeholders or groups related to the project (such as users, community, industry, and environment groups). Some requirements are usually set that somehow adjust the amount of achievement of the goals under their influence [9, 10]. For example, the chosen location of an emergency escape ramp should meet the goals of selected groups, requirements such as avoiding the development of unsuitable locations, reducing the environmental impact of construction and operation in one location, and directing the vehicles to an area with existing infrastructure for sustainable development. In fact, it is the observance of these requirements that balances the achievement of goals. Also, emergency escape ramps cannot be placed where there are some constraints to the geometric design, such as where there is a precipice on the right side and the dangerous turn is to the right [11].

Due to the fact that a large number of roads in Iran are located in mountainous areas and are considered as busy and transit roads, trucks cross these roads a lot, and by location and the use of such ramps, it is possible to significantly prevent the number of accidents of these trucks, especially on mountain passes and roads. In general, with this research, the location of these ramps can be extended to all similar roads and used in large parts of the country, and in particular, the result of this study can be provided in the regulations of the country. The aim of this study is to identify the factors that have a greater impact on the location of the emergency escape ramp to provide the most suitable place for the construction of this ramp.

Section 2 provides some literature on the present study. The methodology of this research is presented in Section 3, in which the procedure of calculation of the brake temperature of design heavy vehicles as well as the speed by AASHTO Green Book method is presented, and the fuzzy analytic hierarchy process (F-AHP) and the fuzzy technique for order performance by similarity to ideal solution (F-TOPSIS) methods are described. Finally, the results of the research are presented in Section 4. Finally, Section 5 represents the summary of results and provides future directions.

2. Literature Review

In this section, some studies on emergency escape ramp accidents, determining the entering speed of a ramp, the need for a ramp, and the location of the emergency escape ramp, are presented.

The National Cooperative Highway Research Program (NCHRP) compiled one of the most comprehensive studies of emergency escape ramps entitled "A Synthesis of Highway Practice 178 Truck Escape Ramps." The study presented the results of a survey conducted with 27 state Departments of Transportation (DOTs) in the United States. The results of this study revealed the experiences of state DOTs regarding design principles, operation and maintenance practices, and determination of the location of emergency escape ramps [12]. Moreover, there are various studies in the literature focusing on determining the location of emergency escape ramps [13, 14], the design for approaching the ramp [15], analysis of incidents in emergency escape ramps and legal risk mitigation [16], and analysis of aggregate property influences on stopping distance on emergency escape ramps [17].

Zhang and Zhang, researchers at the Ministry of Transportation of China, conducted a statistical analysis of accidents on emergency escape ramps, which have been widely developed in China. Large parts of the complaints in their research were due to improper design and location of emergency escape ramps and unsafe exits from these ramps. They surveyed at least 300 emergency escape ramps. The results showed that the trucks came out of the arrester bed of the ramp and had problems in this section and did not reach the upper section of the ramp and left the ramp altogether, which caused death and severe damages to the trucks and their cargoes [16]. Collisions with vehicles in the arrester beds, vehicles that have previously used the ramp, collisions with guardrails on both sides of the ramp, which will be solved by increasing the width of the ramp, and the conclusion achieved for the causes of these accidents are as follows. Unscientific design and location are often cases in which emergency escape ramps are questioned, which is often affected by severe deceleration, improper granulation, uneven friction, junction angle, improper length, width, etc. [17–20]. Emergency escape ramps often exist because of freight trucks and in the event that the brakes fail, and vehicles such as empty trucks, other light trucks, and passing cars that may enter the ramps can cause improper use of ramps [21–23]. In the maintenance of emergency escape ramps, items such as material granulation, wheel path, guardrails, and lights should also be controlled [14, 24, 25].

Liu et al. conducted a study on determining the speed of emergency escape ramps. They indicated that the reasons for improper use of emergency escape ramps were low research, lack of experience at the site, frequent use and accidents in the ramps, and even lack of courage in drivers to use the ramps [26]. On the other hand, to select the speed value in the design of ramps, in the AASHTO Green Book, the speed has been illustrated as 130 km/h [27]. Another method is the equivalent slope of some forces, in which case it is assumed that the brake is entirely out of order and the vehicle's gravity is equal to the sum of the rolling resistance and air resistance. The energy conservation law is one of the methods of energy conservation that assumes all the potential energy of the vehicle is converted into kinetic energy. The estimated method of obtaining the speed at which the potential energy dissipation is completely converted to kinetic energy is considered as follows:

$$V_x = \sqrt{V_i^2 + 2gh_x}, \qquad (1)$$

where V_x is the speed at distance x from the beginning of the slope, V_i is the initial speed (at the beginning of the slope), g is the gravity acceleration (9.81 m/s^2), and h_x is an altitude difference of distance zero (at the beginning of the slope) [26, 28]. The required length of the arrester bed of emergency escape ramps can also be determined as follows [29]:

$$L = \frac{V^2}{254(i + D_f)}, \qquad (2)$$

where L is the length of the arrester bed, V is the entering speed, i is the slope, and D_f is the rolling resistance. It can also be dangerous for the drivers if the speed at the end of the ramp is more than 40 km/h. In this regard, a value should be added to the ramp entering speed as a safety factor for the intended speed [30]. Liu et al. also indicated in their research that if the collision of the vehicle with the end of the ramp leads to death, 40 km/h should be considered in this field; if the collision causes severe damages, 20 km/h should be regarded; if the collision results in minor damages, 20 km/h should also be taken; finally, they stated that if the collision of the vehicle with the end of the ramp does not lead to any damage, 10 km/h should be considered. Moreover, they showed a speed of 102.2 km/h, which was suitable for more than 99% of cases. Finally, they stated that a speed of 105 km/h could be used, which is a much lower numerical value than 130 km/h that is being used globally [26].

Few studies have been conducted on the location of emergency escape ramps. However, some studies indicated that the ramp location is closely related to brake drum temperature, location of invalid braking, drivers' safety consciousness for using rest areas, the configuration of rest areas, and speed management on downgrade sections [14, 31]. Abdelwahab and Morral conducted a study to determine the need for a location of an emergency truck ramp. Considering the primary purpose of this study that was providing a general framework for determining the need and location of emergency escape ramps, they investigated various factors such as accident rates of uncontrollable trucks, slope length, slope percentage, truck percentage, conditions at the bottom of the slope, average daily traffic, horizontal curvature, crash severity, accessibility priority, and topography. Factors that were very important in the location of the ramp were the intensity of the slope, i.e., its length and amount, the limitation of turns, such as the speed of turns in horizontal curves, the accident records, i.e., the repetition of previous accidents, and the consequences of accidents, i.e., the probability of death at the expected location (conditions at the bottom of the slope). They indicated that determining the need for an emergency escape ramp for a slope included the following measures: (1) selecting the design vehicle, (2) brake temperature, and (3) having a brake check area at the top of the slope. Finally, they stated that emergency escape ramps could then be prioritized for installation in the most-guaranteed to the least-guaranteed areas [13]. Zhou et al. used a technique for escape ramp location determination in China's mountain area expressway. In this study, an integrated technique of escape ramp configuration, which covers speed management measures, brake drum temperature, and emergency stopping demand, as well as rest area configuration, was discussed based on the Hebei-Shanxi Expressway. The steps for the location of the escape ramps at the mountain expressways of this research were the definition of long continuous downgrade section, calculation of brake drum temperature to estimate the initial location of escape ramps, final configuration of escape ramp due to construction constraints, and verification of load weight-based speed management [14]. Song et al. conducted a study to determine the optimal location for the escape ramp in the vicinity of expressway tunnels in mountainous areas. They analyzed the influence of rear-end crashes, lane-changing behavior, emergency braking behavior, and traffic safety facilities on the location of the ramp. The results indicated that the minimum distance between the escape ramp and tunnel exits should be no less than 650 m under any circumstances. Also, the minimum distance between the escape ramp and tunnel entrances should be no less than 260 m [32].

Due to a large number of trucks on the roads and especially on two-lane highways, which cover a huge amount of passing traffic, controlling these vehicles by creating emergency escape ramps can greatly help the traffic flow and prevent subsequent damages. So far, although practical solutions have been taken in designing this type of ramp, few studies have been conducted on the location and finding a suitable way to choose an appropriate location for these ramps. Moreover, the location of emergency escape ramps on two-lane rural highways in northwestern Iran has not yet been determined. So, in this research, according to the importance of emergency escape ramps and identifying a suitable location to design these ramps, two common methods were presented from the analysis of criteria, with the importance of criteria explored by F-AHP. Finally, the appropriate location of the emergency escape ramp was proposed using F-TOPSIS.

3. Methodology

In this study, due to the content of the selected subject, research resources in the study country, Iran, were limited. By designing survey questionnaires and distributing them among experts, effective factors on location of emergency escape ramps were identified on the two-lane rural highways of Salavat Abad village pass of Sanandaj city, Kurdistan Province, Iran, and by referring to the Department of Roads and Urban Development in Kurdistan Province, Iran, data and other required information, including the variables that had a greater effect on the location of the ramp, were collected. Also, by referring to the traffic police of Kurdistan Province, the accident statistics, especially the accident rates of uncontrollable trucks and the technical specifications of the trucks that had more traffic, were obtained, and by the

use of the F-AHP model and designing survey questionnaires, different criteria were reviewed and compared, and finally, the appropriate location of the ramp was proposed using the F-TOPSIS model.

3.1. Brake Temperature of Design Heavy Vehicles.

In this scenario, by setting the speed at 100 km/h and the weight of the vehicle at 40 tons, according to (3), the brake temperature diagram of the vehicle along the route was obtained. During the study route, for every 50 meters, the percentage of longitudinal slope that affected the Myers formula was collected from the road surface so that the error approaches zero.

$$T = T_0 + \left(T_\infty - T_0 + K_2 \times H_{PB}\right)\left(1 - e^{\left(-k_1 x/v\right)}\right), \qquad (3)$$

where $T_\infty = 90°F$ and $T_0 = 150°F$, and

$$k_1 = 1.23 + 0.256\,\overline{v}\,(1/\text{hr}),$$

$$k_2 = (0.100 + 0.00208\,\overline{v})^{-1}\left(\text{of}/h_p\right),$$

$$\text{HP}_B = \left(W.g - F_{\text{drag}}\right)\frac{\overline{v}}{375} - \text{HP}_{\text{ang}},$$

$$F_{\text{drag}} = 450 + 17.25\,\overline{v}, \qquad (4)$$

$$\text{HP}_{\text{ang}} = 7.3 + 100\,k_{\text{ret}},$$

$$k_{ret} = \begin{cases} 0, & \text{engine broke off,} \\ 0.5, & \text{engine broke low,} \\ 1.0, & \text{engine broke high,} \end{cases}$$

where W is the total truck weight (*lb*) and the other variables are already defined. According to the survey, the trucks used a speed of 70 km/h along the route, which reached 100 km/h for the trucks after a defect in the braking system.

3.2. Speed Calculation by the AASHTO Green Book.

In this scenario, three modes can be considered to calculate the speed initially used by the passing vehicles:

(1) Design speed (speed limit signs)
(2) Speed used (the speed at which drivers descend the pass regardless of the traffic police)
(3) Mean speed of the first and second modes

In this study, the second mode was used, which was about 70 km/h.

After considering the speed of the trucks while entering the emergency escape ramp, the following items were obtained from interpolation and extrapolation in Figure 1 that is presented from the AASHTO Green Book [27]:

(1) In the first option (before the second tunnel), the length of the slope was 150 meters, the slope was 1.5%, and the speed of entering the ramp was equal to the same 70 km/h

(2) In the second option (Akbar Joojeh), the length of the slope was 550 meters, the slope was 5%, and the speed of entering the ramp was 95 km/h

(3) In the third option (Salavat Abad village entrance), the length of the slope was 550 meters, the slope was 5%, and the speed of entering the ramp was 95 km/h

(4) In the fourth option (after Razm Ara), the length of the slope was 700 meters, the slope was 7.2%, and the speed of entering the ramp was 110 km/h

(5) In the fifth option (Kurkur turn 1), the length of the slope was 155 meters, the slope was 6%, and the speed of entering the ramp was 80 km/h

(6) In the sixth option (Kurkur turn 2), the length of the slope was 350 meters, the slope was 6.2%, and the speed of entering the ramp was 90 km/h

(7) In the seventh option (before the police inspection station), the length of the slope was 1600 meters, the slope was 6%, and the speed of entering the ramp was 125 km/h

3.3. Statistical Analysis.

One of the most important types of decision-making models is multiple-criteria decision making (MCDM) which helps a researchers choose the best one when faced with several different criteria for selection. MCDM generally is divided into two categories of multi-objective decision making (MODM) and multiple-attribute decision making (MADM). MODM is mostly used for design in continuous decision situations. In this model, several objectives are considered simultaneously, while MADM is applied to choose the best option in discontinuous decision situations, which is the goal of this study. Therefore, MADM methods should be used to investigate the location problem of the emergency escape ramp because the space for solving such problems is not continuous and there are often a number of predefined options. MADM methods are performed with the objectives of ranking criteria and subcriteria (for example, using AHP and analytic network process (ANP)) and ranking as well as selecting the optimal option (for example, using TOPSIS and VIKOR). Each method is based on a series of hypotheses. For instance, if the criteria are independent of each other and pairwise comparisons are possible, the appropriate decision model is the AHP method, but if the criteria are not independent, the ANP method is better. Moreover, the VIKOR method uses the concept of the worst option in order to rank and find the
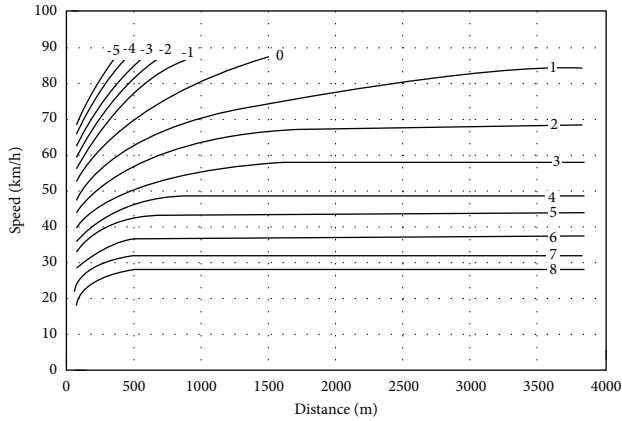
FIGURE 1: Increased acceleration in the slope [27].

FIGURE 2: Schematic representation of a hierarchical problem.

best option, while in TOPSIS, two options of positive ideals and negative ideals are created, based on the concept of the closest solution to the final ideal and the farthest solution from the negative ideal. Therefore, the choice of each of these methods is made by the researcher according to the purpose of the study and the structure of the data. So, in this research, the importance of criteria was examined by F-AHP and the high priority options were illustrated using F-TOPSIS [33–35], which have been described in the following. It should be noted that the type of criteria in AHP is quantitative and qualitative, the number of criteria in this method cannot be great, its logic is weaker than TOPSIS and is not suitable for problems with a large number of criteria, and also, the performance of this method in prioritizing criteria or paired options; while the type of criteria in TOPSIS is quantitative and qualitative, it can be performed with a large number of criteria, it does not weigh the criteria against each other, and it is not applicable without options, and finally, the performance of this method is only in prioritization options [36].

3.3.1. F-AHP Algorithm

(1) Creating a Hierarchical Structure. A hierarchical structure is a graphical representation of a problem in which the purpose of the problem, the decision criteria, and the proposed options are shown as the main elements, as illustrated in Figure 2. In fact, at this stage, the problem should be defined, the criteria should be determined, and the proposed options should be identified so that the structure can be formed and the relationships of each section with other sections can be displayed on it. It should also be noted that decision-making criteria, depending on the complexity of the problem, can have several layers and each can be divided into a number of subcriteria [37, 38].

(2) Performing Pairwise Comparison(s). Once the group has agreed on the hierarchy, pairwise comparison matrices can be developed at each level. This stage begins with the design of appropriate questionnaires to perform all necessary pairwise comparisons. In the AHP method, pairwise
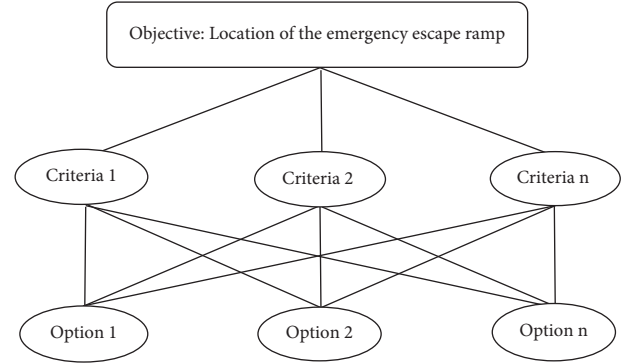
comparisons are made between the elements of each level relative to the corresponding higher-level element. In other words, at this stage, the relative importance (weight) of the criteria relative to each other (according to the problem purpose), as well as the status of the options relative to each other (according to the criteria), is determined. Of course, these judgments are equated with quantitative values between 1 and 9 and are eventually used fuzzily, as illustrated in Table 1 [39–42].

The output of the judgments made in the above-mentioned method makes it possible to create a number of specific pairwise comparison matrices, which are in the following form [43, 44]:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & a_{ij} & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}, \tag{5}$$

where a_{ij} is the preference of the element i over the element j, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. Using the above-mentioned matrix, the relative weight of the elements can be calculated. It should be noted that, in pairwise comparison matrices, row i is compared with column j. Therefore, all the elements of the main diagonal of this matrix are one. Also, any value below the main diagonal is the inverse of the value above the diagonal. By specifying a_{ij}, relative weights, i.e., w_i, can be obtained [45–48].

(3) Determining the Final Priority of Indicators. In this step, it is tried to determine the absolute weight (priority) of each subcriterion by using the results of pairwise comparison matrices that determine the relative weight. The final weight of each option in an AHP is obtained by multiplying the importance of the criteria by the weight of the subcriterion [49, 50].

3.3.2. F-TOPSIS Method.
Solving the problem with this method requires the following six steps [51]:

(1) Quantifying the Decision Matrix. In this method, each element of the decision matrix is divided by the sum of the root squares of the elements in each column [51]:

TABLE 1: Preference values for pairwise comparisons.

Degree of superiority	Description	Explanation
1	Equal importance	Two criteria are equally important in achieving the goal
3	Slightly more important	Experience shows that i is slightly more important than j
5	More important	Experience shows that i is more important than j
7	Much more important	Experience shows that i is much more important than j
9	Absolutely more important	The absolute significance of i over j is definitely proved
2, 4, 6, and 8	—	When there are intermediate modes

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}, \tag{6}$$

where n_{ij} is the unscaled value of the option i in terms of the index j and other variables are predefined.

(2) Obtaining the Weighted Unscaled Matrix (V). The unscaled matrix from the first step is multiplied by the diagonal matrix of weights ($W_{n \times n}$), as illustrated in the following equation:

$$V = N \times W_{n \times n}, \tag{7}$$

where N is a matrix in which the scores of the indices are unscaled and comparable and $W_{n \times n}$ is a diagonal matrix in which only the elements of the main diagonal are nonzero [51].

(3) Determining the Positive and Negative Ideal Solutions. In this step, a positive ideal solution (v_j^+) and a negative ideal solution (v_j^-) are calculated for each indicator. Positive and negative ideal solutions are defined as follows [51]:

[Vector of the best values of each indicator of the matrix V] = positive ideal solution (v_j^+)

[Vector of the worst values of each indicator of the matrix V] = negative ideal solution (v_j^-)

Moreover, it can be said that [52, 53]

(i) For each positive indicator, the positive ideal solution is the largest value of the corresponding column in the matrix V

(ii) For each positive indicator, the negative ideal solution is the smallest value of the corresponding column in the matrix V

(iii) For each negative indicator, the positive ideal solution is the smallest value of the corresponding column in the matrix V

(iv) For each negative indicator, the negative ideal solution is the largest value of the corresponding column in the matrix V

(4) Obtaining the Distance of Options to Ideal Solutions. The Euclidean distance of each option to the positive ideal (d_j^+) and the distance of each option to the negative ideal (d_j^-) are calculated based on the following equations [51]:

$$d_j^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \quad i = 1, 2, \ldots, m, \tag{8}$$

$$d_j^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \quad i = 1, 2, \ldots, m. \tag{9}$$

(5) Determining the Relative Proximity. In determining the relative proximity (*CL*) of an option to the ideal solution, it should be noted that moving away from the nonideal point does not necessarily mean moving closer to the ideal point. Therefore, the following equation is used to evaluate the options [51]:

$$CL = \frac{\text{Distance from nonideal limit}}{\text{The sum of the distances from the ideal and the nonideal solutions}}$$

$$= \frac{d_j^-}{d_j^- + d_j^+}, \quad 0 \le CL \le 1. \tag{10}$$

(6) Ranking the Options. In this step, the options are ranked based on the descending order of the *CL s*. Any option with a larger *CL* is better [51].

4. Results and Discussion

4.1. Vehicle Brake Temperature Diagram. As can be seen, Figure 3 shows the brake temperature of the vehicle along the route from the peak point of Salavat Abad village pass to Sanandaj city. Also, Figure 4 indicates the vehicle brake temperature along the route from the peak point of Salavat Abad village pass to the opposite direction of Sanandaj city (police inspection station).

In the investigation process, the options that could not be implemented were removed, and as can be seen, all the options were on the red line, which means that the possibility of vehicle brake failure was very high. However, there are two options 1 and 7 below the red line, which was added
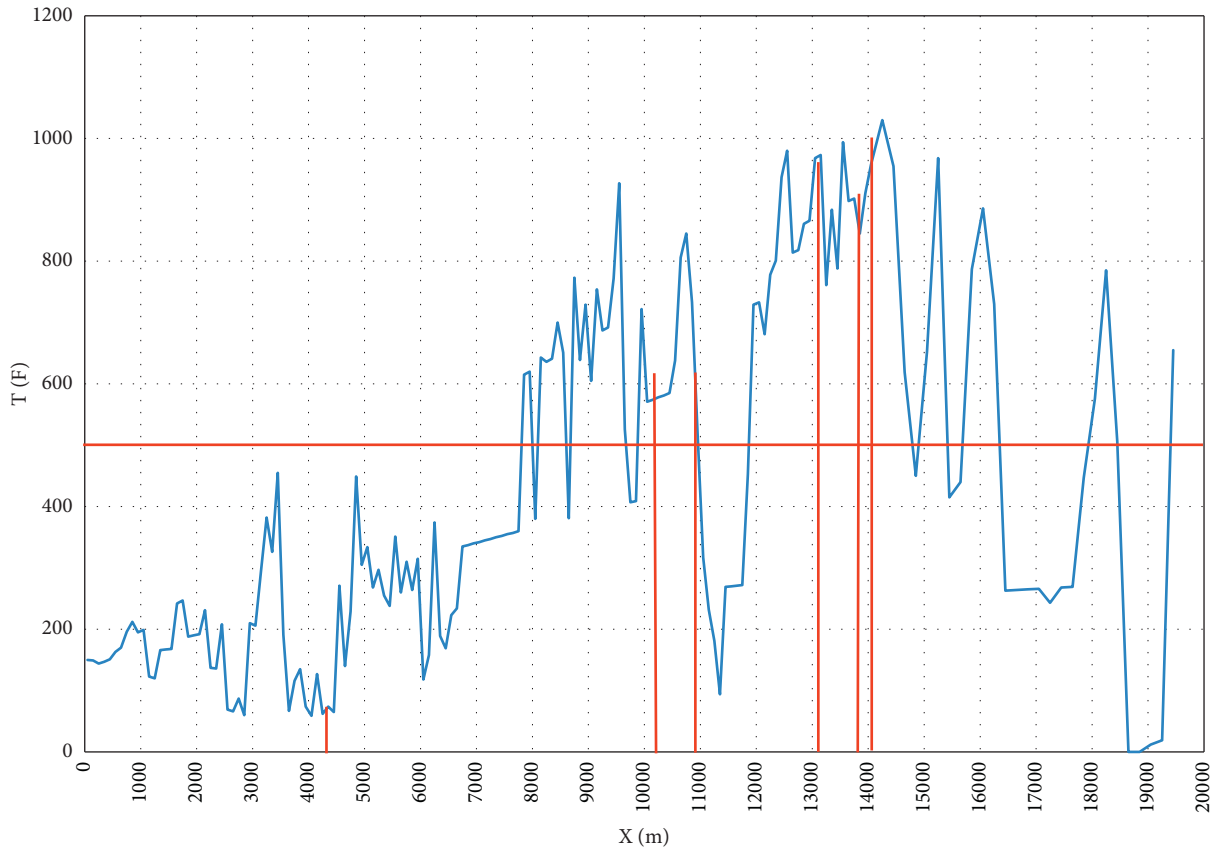
FIGURE 3: Brake temperature diagram along the route towards Sanandaj city.
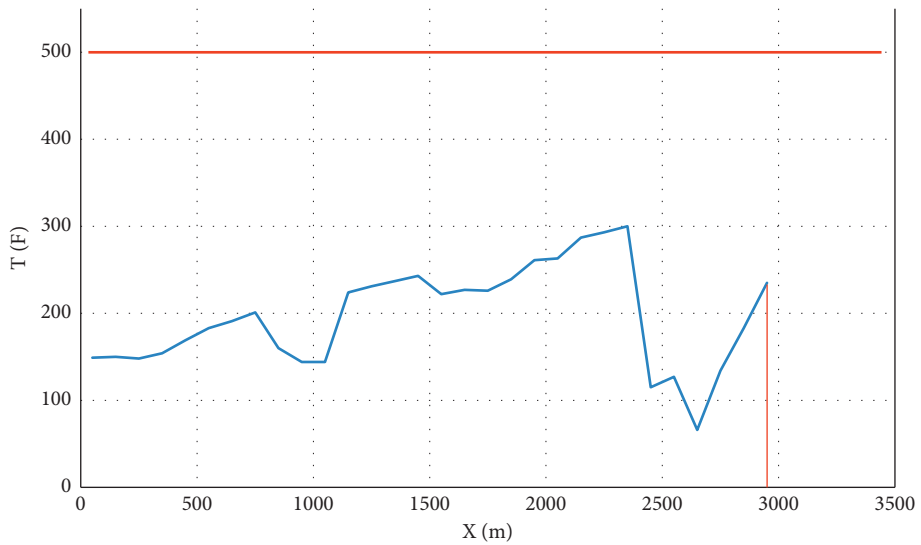
FIGURE 4: Brake temperature diagram along the route towards the police inspection station.

according to the opinion of the experts and police officers, which were finally able to use the validation power of the experts in the questionnaires.

4.2. Identifying the Research Criteria and Options. In the first step, study options were identified and selected, which were performed based on previous studies in the field of ramps

and local experts. The main criteria of the study were technical, economic, and other factors. A total of 3 criteria and 16 subcriteria were identified. In this step, research literature and specialized interviews were used to identify the criteria. Also, the criteria and research options are illustrated in Table 2 with a numerical indicator so that they can be easily traced and studied during the research.

4.3. Determining the Priority of Main Criteria.

In order to perform the network analysis, the main criteria were first compared in pairs based on the purpose. Pairwise comparison is very simple, and all elements of each cluster should be compared in pairs. Therefore, if there are n elements in a cluster, $n(n - 1)/2$ comparisons will be made. Because there were 3 criteria, the number of comparisons made was

$$\frac{n(n - 1)}{2} = \frac{3(3 - 1)}{2} = 3. \tag{11}$$

Therefore, 3 pairwise comparisons were performed from the opinion of a group of experts. The opinion of experts was quantified using a fuzzy scale. First, the opinion of experts was collected with a range of nine degrees followed by fuzzification. The geometric mean method was used to aggregate the opinion of experts in the F-AHP method. According to the results of aggregating the opinion of experts, the pairwise comparison matrix is presented in Table 3.

After forming the pairwise comparison matrix obtained from Table 3, the special vector was calculated. First, the fuzzy sum of each row was calculated. Then, the fuzzy sum of the total elements of the preference column was calculated. Therefore, the sum of the elements of the preference column of the main criteria was as follows:

$$\sum_{i=1}^{3} \sum_{j=1}^{3} M_{ij} = (13.619, 15.485, 17.482), \tag{12}$$

where M_{ij} is a triangular fuzzy number. In order to normalize the preferences of each criterion, the sum of the values of that criterion must be divided by the sum of all the preferences (column elements). Because the values are fuzzy, the fuzzy sum of each row is multiplied by the inverse of the sum to present S_k. The inverse of the sum (F_s^{-1}) must be calculated:

$$F_s^{-1} = \left(\frac{1}{u_s}, \frac{1}{m_s}, \frac{1}{l_s} \right) = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} M_g^j \right)^{-1} = (0.057, 0.065, 0.073),$$

$$S_k = \sum_{i=1}^{n} M \times \left(\sum_{i=1}^{n} \sum_{j=1}^{n} M_g^j \right)^{-1}. \tag{13}$$

Therefore, the results of normalization of the obtained values of the main criteria (as illustrated in Table 2) were as follows:

$$C1 = (0.553, 0.698, 0.899),$$
$$C2 = (0.151, 0.186, 0.244), \tag{14}$$
$$C3 = (0.095, 0.116, 0.141).$$

Each of the obtained values of fuzzy and normalized weight corresponded to the main criteria. In the final step, defuzzification of the obtained values and calculations of the crisp number were performed [54, 55]. The calculations performed to prioritize the main criteria are as shown in Table 4.

According to Table 4, the eigenvector of priority of the main criteria (W) was as follows:

$$W = \begin{pmatrix} 0.695 \\ 0.190 \\ 0.115 \end{pmatrix}. \tag{15}$$

Based on the final normalized weight obtained and Figure 5,

(i) The technical criterion with a normal weight of 0.695 had the highest priority

(ii) The economic criterion with a normal weight of 0.190 had the second priority

(iii) Other factors with a normal weight of 0.115 had the last priority

4.4. Prioritizing the Technical Subcriteria.

The technical subcriteria used in this research were longitudinal slope length, percentage of longitudinal slope, vehicle design speed, available right of way, horizontal curve radius, physical development capability, and traffic level of service. The opinion of a group of experts was also used and collected in this section. The geometric mean of the opinion of the experts was conducted in the calculations to determine the priority of the technical subcriteria that is presented in Table 5.

The summary of defuzzification calculations of values is also shown in Table 6.

Based on the final normalized weight obtained and Figure 6,

(i) The percentage of the longitudinal slope with a normal weight of 0.283 had the highest priority

(ii) The longitudinal slope length with a normal weight of 0.272 had the second priority

(iii) The vehicle design speed with a normal weight of 0.157 had the third priority

(iv) The horizontal curve radius with a normal weight of 0.084 had the fourth priority

(v) The physical development capability with a normal weight of 0.077 had the fifth priority

(vi) The available right of way with a normal weight of 0.075 had the sixth priority

TABLE 2: Criteria and research options.

Criterion	Criterion symbol	Subcriterion	Subcriteria symbol
Technical	C1	Longitudinal slope length	S11
		Percentage of longitudinal slope	S12
		Vehicle design speed	S13
		Available right of way	S14
		Horizontal curve radius	S15
		Physical development capability	S16
		Traffic level of service	S17
Economic	C2	Cost of land acquisition	S21
		Construction cost (volume of earthworks)	S22
		Operational costs	S23
Other factors	C3	Accident statistics (uncontrollable trucks)	S31
		Percentage of passing trucks	S32
		Average daily traffic	S33
		Access to public road services	S34
		Conditions at the bottom of the longitudinal slope	S35
		Environmental effects	S36

TABLE 3: Pairwise comparison matrix of the main criteria of the research.

	C1			C2			C3		
C1	1	1	1	5594	4804	4026	5646	5001	4287
C2	0.248	0.208	0.179	1	1	1	2079	1675	1469
C3	0.233	0.200	0.177	0.681	0.597	0.481	1	1	1

TABLE 4: Defuzzification of calculated normalized weights of the main study variables.

Crisp	X_{1max}	X_{2max}	X_{3max}	Defuzzification	Normal
Technical	0.710	0.707	0.704	0.710	0.695
Economical	0.194	0.192	0.190	0.194	0.190
Other factors	0.117	0.117	0.117	0.117	0.115

(vii) The traffic level of service with a normal weight of 0.053 had the last priority

4.5. Prioritizing the Economic Subcriteria. The economic subcriteria used in this study were cost of land acquisition, construction cost (volume of earthworks), and operational costs. The opinion of a group of experts was also applied and collected in this section. The geometric mean of the opinion of the experts was performed in the calculations to specify the priority of the economic subcriteria that is represented in Table 7.

Moreover, the summary of defuzzification calculations of values is illustrated in Table 8.

Based on the final normalized weight obtained and Figure 7,

(i) The cost of land acquisition with a normal weight of 0.423 had the highest priority

(ii) The operational costs with a normal weight of 0.292 had the second priority

(iii) The construction cost (volume of earthworks) with a normal weight of 0.285 had the third priority

4.6. Prioritizing the Other Factor Subcriteria. The other factor subcriteria presented in this research were accident statistics (uncontrollable trucks), percentage of passing trucks, average daily traffic, access to public road services, conditions at the bottom of the longitudinal slope, and environmental effects. Also, the opinion of the experts was applied, and the geometric mean of which was conducted in the calculations to determine the priority of the other factor subcriteria that is illustrated in Table 9.

In addition, the summary of defuzzification calculations of values is presented in Table 10.

Based on the final normalized weight obtained from Table 10 and represented in Figure 8,

(i) The accident statistics (uncontrollable trucks) with a normal weight of 0.372 had the highest priority

(ii) The percentage of passing trucks with a normal weight of 0.282 had the second priority

(iii) The average daily traffic with a normal weight of 0.189 had the third priority

(iv) The access to public road services with a normal weight of 0.102 had the fourth priority

(v) The environmental effects with a normal weight of 0.030 had the fifth priority

(vi) The conditions at the bottom of the longitudinal slope with a normal weight of 0.024 had the last priority

4.7. Final Priority of Indicators by AHP. In this step, the final priority of the research indicators was calculated. The results of comparing the research subcriteria and their weighting formed the W_2 matrix. In order to determine the final priority of the indicators by the AHP method, it is enough to multiply the weight of the indicators based on each criterion (W_2) by the weight of the main criteria (W_1). Having the weight of each of the main criteria (W_1) and subcriteria (W_2), the weight of each of the indicators is calculated
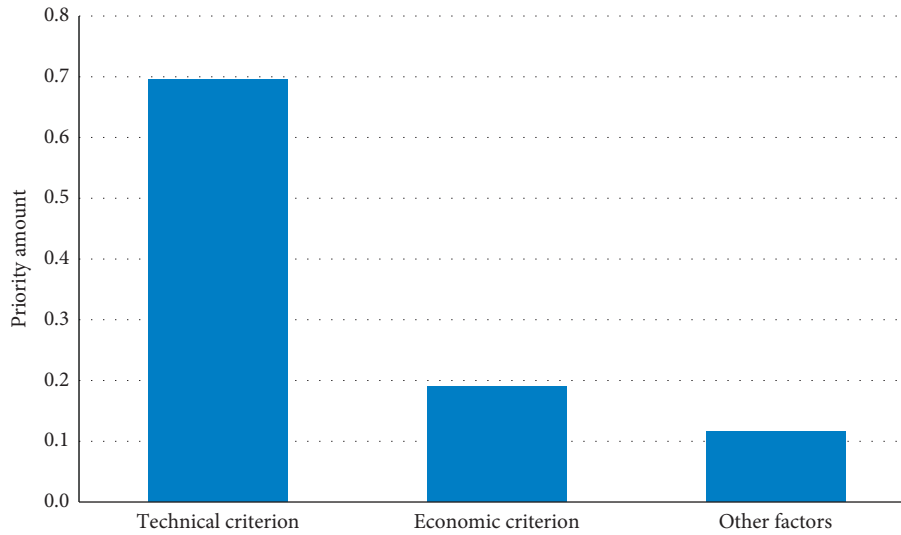
FIGURE 5: Representation of the priority of the main criteria in the research.

TABLE 5: Prioritizing the technical subcriteria.

	S11	S12	S13	S14	S15	S16	S17
	1	0.585	0.475	0.294	0.39	0.299	0.328
S11	1	0.504	0.382	0.242	0.331	0.256	0.278
	1	0.44	0.319	0.204	0.290	0.225	0.241
	2.27	1	0.368	0.375	0.319	0.22	0.274
S12	1.986	1	0.315	0.308	0.275	0.191	0.235
	1.711	1	0.272	0.258	0.244	0.169	0.204
	3.131	3.67	1	0.437	0.719	0.413	0.436
S13	2.62	3.179	1	0.368	0.61	0.331	0.386
	2.105	2.715	1	0.316	0.528	0.281	0.348
	4.891	3.87	3.165	1	2.309	0.738	0.738
S14	4.132	3.246	2.714	1	1.943	0.652	0.636
	3.402	2.669	2.29	1	1.583	0.583	0.552
	3.45	4.092	1.894	0.632	1	2.309	0.738
S15	3.018	3.637	1.638	0.515	1	1.943	0.652
	2.564	3.139	1.391	0.433	1	1.583	0.583
	4.446	5.901	3.563	1.716	0.632	1	0.886
S16	3.908	5.237	3.024	1.533	0.515	1	0.755
	3.344	4.542	2.421	1.354	0.433	1	0.621
	4.152	4.895	2.871	1.813	1.716	1.609	1
S17	3.597	4.261	2.591	1.573	1.533	1.324	1
	3.046	3.645	2.291	1.354	1.354	1.129	1

TABLE 6: Defuzzification and determination of the definite weight of technical subcriteria.

Crisp	X_{1max}	X_{2max}	X_{3max}	Defuzzification	Normal
Longitudinal slope length	1531.214	1525.129	1519.045	1531.214	0.272
Percentage of longitudinal slope	1591.104	1584.986	1578.869	1591.104	0.283
Vehicle design speed	880.810	877.480	874.151	880.810	0.157
Available right of way	420.210	418.146	416.081	420.210	0.075
Horizontal curve radius	470.912	468.606	466.300	470.912	0.084
Physical development capability	434.312	431.668	429.023	434.312	0.077
Traffic level of service	298.410	297.103	295.797	298.410	0.053
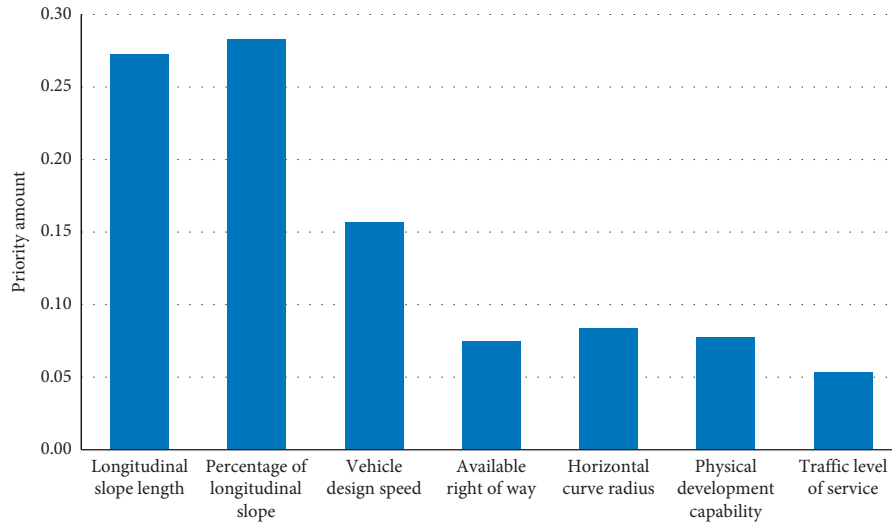
Figure 6: Representation of the prioritization of technical subcriteria.

Table 7: Prioritizing the economic subcriteria.

	S21	S22	S23
	1	1.829	1.615
S21	1	1.607	1.333
	1	1.374	1.084
	0.728	1	1.149
S22	0.622	1	1.035
	0.547	1	0.928
	0.922	1.078	1
S23	0.750	0.966	1
	0.619	0.871	1

Table 8: Defuzzification and determination of the definite weight of economic subcriteria.

Crisp	X_{1max}	X_{2max}	X_{3max}	Defuzzification	Normal
Cost of land acquisition	0.429	0.427	0.426	0.429	0.423
Construction cost (volume of earthworks)	0.289	0.288	0.287	0.289	0.285
Operational costs	0.296	0.295	0.294	0.296	0.292

Figure 7: Display of the prioritization of economic subcriteria.

TABLE 9: Prioritizing the other factor subcriteria.

	S31	S32	S33	S34	S35	S36
	1	0.6	0.636	0.324	0.37	0.382
S31	1	0.508	0.534	0.265	0.307	0.324
	1	0.436	0.455	0.225	0.263	0.282
	2.291	1	0.479	0.458	0.527	0.581
S32	1.969	1	0.394	0.511	0.507	0.466
	1.668	1	0.338	0.338	0.338	0.38
	2.199	2.961	1	0.624	0.634	0.704
S33	1.871	2.54	1	0.511	0.507	0.58
	1.573	2.088	1	0.436	0.425	0.482
	4.441	3.184	2.291	1	1.412	1.172
S34	3.778	2.698	1.958	1	1.141	1.03
	3.089	2.182	1.601	1	0.922	0.901
	3.809	2.961	2.351	1.084	1	1.412
S35	3.263	2.425	1.972	0.876	1	1.141
	2.705	1.898	1.578	0.708	1	0.922
	3.548	2.628	2.076	1.11	1.084	1
S36	3.086	2.147	1.724	0.97	0.876	1
	2.615	1.721	1.421	0.853	0.708	1

TABLE 10: Defuzzification and determination of the definite weight of other factor subcriteria.

Crisp	X_{1max}	X_{2max}	X_{3max}	Defuzzification	Normal
Accident statistics (uncontrollable trucks)	0.385	0.382	0.379	0.385	0.372
Percentage of passing trucks	0.292	0.289	0.287	0.292	0.282
Average daily traffic	0.196	0.194	0.192	0.196	0.189
Access to public road services	0.105	0.105	0.104	0.105	0.102
Conditions at the bottom of the longitudinal slope	0.025	0.025	0.025	0.025	0.024
Environmental effects	0.031	0.031	0.031	0.031	0.030

[56, 57]. The results of the calculation and weighting related to the indicators are presented in Table 11.

Therefore, based on the results and Figure 9, the percentage of longitudinal slope with a final weight of 0.197 was the first priority, the longitudinal slope length with a final weight of 0.189 was the second priority, and the vehicle design speed with a weight of 0.109 was the third priority of the most important subcriteria.

4.8. Selecting an Option by TOPSIS. In this study, the TOPSIS method was used to select the best suitable option (suitable location for emergency escape ramps for trucks that had problems on the roads (brakes cut)). The best location is the one that has the most distance from the negative factors and the least distance from the positive factors. For this aim, the following steps were performed.

4.8.1. Identifying the Criteria and Options. The main indicators (criteria) and options were identified. Therefore, the scoring matrix of the options was formed based on the subcriteria. A nine-point Likert scale was used to score the best option based on each criterion. The appropriate score for each of the options based on the indicators according to the simple average of expert opinions is presented in Table 12.

4.8.2. Preparing the Unscaled Matrix. The unscaled matrix is denoted by N, and each element is denoted by n_{ij}. Each element of this matrix was calculated according to equation (6). Therefore, F-TOPSIS for the unscaled matrix N is presented in Table 13.

4.8.3. Preparing the Weighted Unscaled Matrix. In the third step, the unscaled matrix (N) must be converted to the weighted unscaled matrix (V). In order to obtain a weighted unscaled matrix, the weights of the indicators must be known. The weight of each indicator was calculated using the F-AHP technique, which is presented in Table 11. For this purpose, the unscaled matrix N must be multiplied by the square matrix $W_{n \times n}$, whose main diagonal elements are the weights of the indicators and the other elements are zero. The result of this calculation is summarized in Table 14.

4.8.4. Calculating the Ideal Solutions. The positive and negative ideal values for this decision situation are represented in Table 15.

4.8.5. Calculating the Distance of Options to Ideal Solutions. The calculations for this step were performed according to equations (8) and (9), and the output of F-TOPSIS for these equations is illustrated in Table 16.
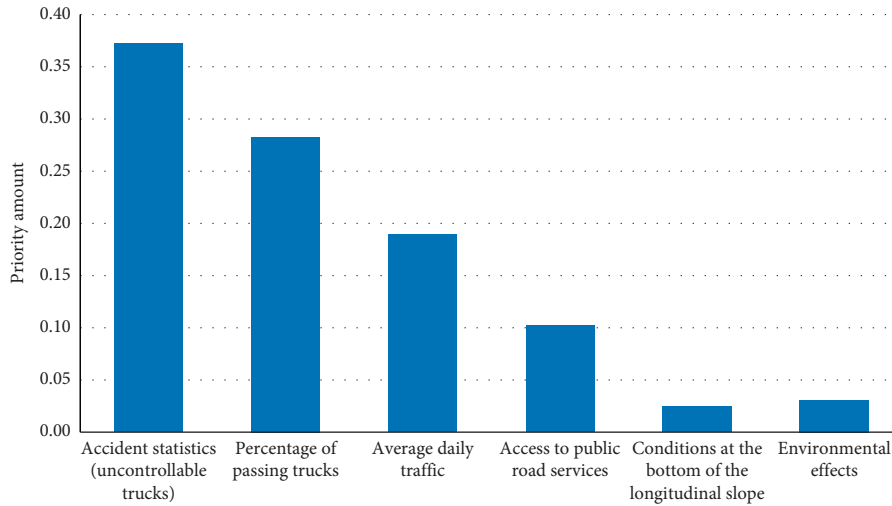
FIGURE 8: Display of prioritizing subcriteria of other factors.

TABLE 11: Final priority of research subcriteria.

Criterion	Criterion weight	Subcriterion	Subcriterion weight	Final weight
		Longitudinal slope length	0.272	0.189
		Percentage of longitudinal slope	0.283	0.197
		Vehicle design speed	0.157	0.109
Technical	0.695	Available right of way	0.075	0.052
		Horizontal curve radius	0.084	0.058
		Physical development capability	0.077	0.054
		Traffic level of service	0.053	0.037
		Cost of land acquisition	0.423	0.080
Economic	0.19	Construction cost (volume of earthworks)	0.285	0.054
		Operational costs	0.292	0.056
		Accident statistics (uncontrollable trucks)	0.372	0.043
		Percentage of passing trucks	0.282	0.032
		Average daily traffic	0.189	0.022
Other factors	0.115	Access to public road services	0.102	0.012
		Conditions at the bottom of the longitudinal slope	0.024	0.003
		Environmental effects	0.030	0.003
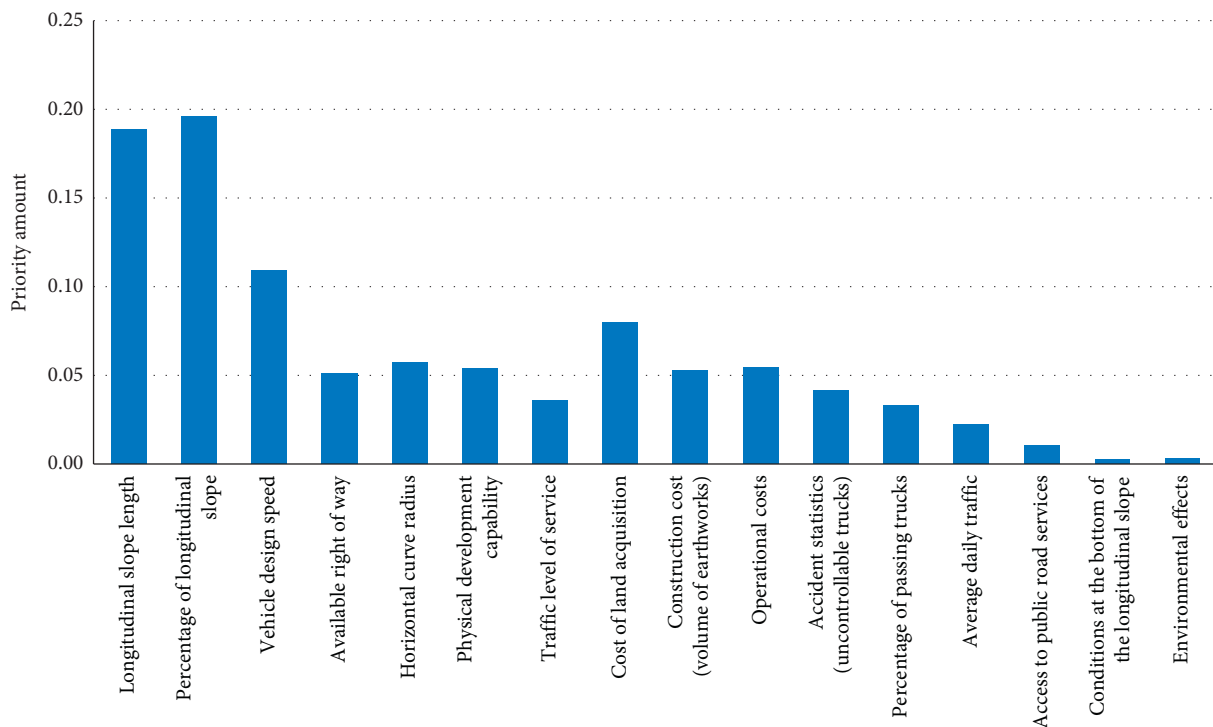
FIGURE 9: Final priority of research subcriteria.

TABLE 12: TOPSIS technique decision matrix.

M	Option 1 (before the second tunnel)	Option 2 (Akbar Joojeh)	Option 3 (Salavat Abad entrance)	Option 4 (after Razm Ara)	Option 5 (Kurkur turn 1)	Option 6 (Kurkur turn 2)	Option 7 (before the police inspection station)
	4.15	4.45	5.05	5.05	5.25	5.45	4
S11	3.15	3.45	4.05	4.05	4.25	4.45	3
	2.15	2.45	3.05	3.05	3.25	3.45	2
	4.05	4.55	5.05	4.85	5.3	5.35	4
S12	3.05	3.55	4.05	3.85	4.3	4.35	3
	2.05	2.55	3.05	2.85	3.3	3.35	2
	4.15	4.4	4.7	4.75	4.9	4.95	4.35
S13	3.15	3.4	3.7	3.75	3.9	3.95	3.35
	2.15	2.4	2.7	2.75	2.9	2.95	2.35
	4.25	4.15	4.35	4.25	4.4	4.45	3.6
S14	3.25	3.15	3.35	3.25	3.4	3.45	2.6
	2.25	2.15	2.35	2.25	2.4	2.45	1.6
	4.1	4.5	4.9	4.75	5.35	5.2	3.3
S15	3.1	3.5	3.9	3.75	4.35	4.2	2.3
	2.1	2.5	2.9	2.75	3.35	3.2	1.3
	3.75	4.25	4.65	4.45	4.95	4.55	4.1
S16	2.75	3.25	3.65	3.45	3.95	3.55	3.1
	1.75	2.25	2.65	2.45	2.95	2.55	2.1
	4.15	4.25	4.55	4.3	4.5	4.5	4.15
S17	3.15	3.25	3.55	3.3	3.5	3.5	3.15
	2.15	2.25	2.55	2.3	2.5	2.5	2.15
	4	4.6	4.4	4.05	4.45	4.35	4.3
S21	3	3.6	3.4	3.05	3.45	3.35	3.3
	2	2.6	2.4	2.05	2.45	2.35	2.3
	4	4.2	4.15	4.4	4.65	4.7	3.8
S22	3	3.2	3.15	3.4	3.65	3.7	2.8
	2	2.2	2.15	2.4	2.65	2.7	1.8
	4.05	4.05	4.2	4.15	4.5	4.55	4.4
S23	3.05	3.05	3.2	3.15	3.5	3.55	3.4
	2.05	2.05	2.2	2.15	2.5	2.55	2.4
	3.95	4.1	4.65	4.35	4.95	5.05	3.7
S31	2.95	3.1	3.65	3.35	3.95	4.05	2.7
	1.95	2.1	2.65	2.35	2.95	3.05	1.7
	4.45	4.5	4.55	4.6	4.65	4.55	4.2
S32	3.45	3.5	3.55	3.6	3.65	3.55	3.2
	2.45	2.5	2.55	2.6	2.65	2.55	2.2
	4.15	4.3	4.55	4.3	4.7	4.65	4.25
S33	3.15	3.3	3.55	3.3	3.7	3.65	3.25
	2.15	2.3	2.55	2.3	2.7	2.65	2.25
	4.1	4.05	4.2	4.05	4.3	4.4	4.05
S34	3.1	3.05	3.2	3.05	3.3	3.4	3.05
	2.1	2.05	2.2	2.05	2.3	2.4	2.05
	4.05	4.45	4.5	4.25	4.8	4.8	4.6
S35	3.05	3.45	3.5	3.25	3.8	3.8	3.6
	2.05	2.45	2.5	2.25	2.8	2.8	2.6
	4.05	3.85	4.15	3.9	4.2	4.1	4
S36	3.05	2.85	3.15	2.9	3.2	3.1	3
	2.05	1.85	2.15	1.9	2.2	2.1	2

TABLE 13: Unscaled decision matrix N.

N	Option 1 (before the second tunnel)	Option 2 (Akbar Joojeh)	Option 3 (Salavat Abad entrance)	Option 4 (after Razm Ara)	Option 5 (Kurkur turn 1)	Option 6 (Kurkur turn 2)	Option 7 (before the police inspection station)
	0.761	0.817	0.927	0.927	0.963	1	0.734
$S11$	0.578	0.633	0.743	0.743	0.78	0.817	0.55
	0.394	0.45	0.56	0.56	0.596	0.633	0.367
	0.757	0.85	0.944	0.907	0.991	1	0.748
$S12$	0.57	0.664	0.757	0.72	0.804	0.813	0.561
	0.383	0.477	0.57	0.533	0.617	0.626	0.374
	0.838	0.889	0.949	0.96	0.99	1	0.879
$S13$	0.636	0.687	0.747	0.758	0.788	0.798	0.677
	0.434	0.485	0.545	0.556	0.586	0.596	0.475
	0.955	0.933	0.978	0.955	0.989	1	0.809
$S14$	0.73	0.708	0.753	0.73	0.764	0.775	0.584
	0.506	0.483	0.528	0.506	0.539	0.551	0.36
	0.766	0.841	0.916	0.888	1	0.972	0.617
$S15$	0.579	0.654	0.729	0.701	0.813	0.785	0.43
	0.393	0.467	0.542	0.514	0.626	0.598	0.243
	0.758	0.859	0.939	0.899	1	0.919	0.828
$S16$	0.556	0.657	0.737	0.697	0.798	0.717	0.626
	0.354	0.455	0.535	0.495	0.596	0.515	0.424
	0.912	0.934	1	0.945	0.989	0.989	0.912
$S17$	0.692	0.714	0.78	0.725	0.769	0.769	0.692
	0.473	0.495	0.56	0.505	0.549	0.549	0.473
	0.87	1	0.957	0.88	0.967	0.946	0.935
$S21$	0.652	0.783	0.739	0.663	0.75	0.728	0.717
	0.435	0.565	0.522	0.446	0.533	0.511	0.5
	0.851	0.894	0.883	0.936	0.989	1	0.809
$S22$	0.638	0.681	0.67	0.723	0.777	0.787	0.596
	0.426	0.468	0.457	0.511	0.564	0.574	0.383
	0.89	0.89	0.923	0.912	0.989	1	0.967
$S23$	0.67	0.67	0.703	0.692	0.769	0.78	0.747
	0.451	0.451	0.484	0.473	0.549	0.56	0.527
	0.782	0.812	0.921	0.861	0.98	1	0.733
$S31$	0.584	0.614	0.723	0.663	0.782	0.802	0.535
	0.386	0.416	0.525	0.465	0.584	0.604	0.337
	0.957	0.968	0.978	0.989	1	0.978	0.903
$S32$	0.742	0.753	0.763	0.774	0.785	0.763	0.688
	0.527	0.538	0.548	0.559	0.57	0.548	0.473
	0.883	0.915	0.968	0.915	1	0.989	0.904
$S33$	0.67	0.702	0.755	0.702	0.787	0.777	0.691
	0.457	0.489	0.543	0.489	0.574	0.564	0.479
	0.932	0.92	0.955	0.92	0.977	1	0.92
$S34$	0.705	0.693	0.727	0.693	0.75	0.773	0.693
	0.477	0.466	0.5	0.466	0.523	0.545	0.466
	0.844	0.927	0.938	0.885	1	1	0.958
$S35$	0.635	0.719	0.729	0.677	0.792	0.792	0.75
	0.427	0.51	0.521	0.469	0.583	0.583	0.542
	0.964	0.917	0.988	0.929	1	0.976	0.952
$S36$	0.726	0.679	0.75	0.69	0.762	0.738	0.714
	0.488	0.44	0.512	0.452	0.524	0.5	0.476

TABLE 14: Weighted unscaled matrix V.

V	Option 1 (before the second tunnel)	Option 2 (Akbar Joojeh)	Option 3 (Salavat Abad entrance)	Option 4 (after Razm Ara)	Option 5 (Kurkur turn 1)	Option 6 (Kurkur turn 2)	Option 7 (before the police inspection station)
	0.144	0.154	0.175	0.175	0.182	0.189	0.139
$S11$	0.109	0.12	0.141	0.141	0.148	0.154	0.104
	0.075	0.085	0.106	0.106	0.113	0.12	0.069
	0.149	0.167	0.186	0.178	0.195	0.197	0.147
$S12$	0.112	0.13	0.149	0.141	0.158	0.16	0.11
	0.075	0.094	0.112	0.105	0.121	0.123	0.073
	0.091	0.097	0.103	0.104	0.108	0.109	0.096
$S13$	0.069	0.075	0.081	0.082	0.086	0.087	0.074
	0.047	0.053	0.059	0.06	0.064	0.065	0.052
	0.05	0.048	0.051	0.05	0.051	0.052	0.042
$S14$	0.038	0.037	0.039	0.038	0.04	0.04	0.03
	0.026	0.025	0.027	0.026	0.028	0.029	0.019
	0.045	0.049	0.053	0.052	0.058	0.057	0.036
$S15$	0.034	0.038	0.042	0.041	0.047	0.046	0.025
	0.023	0.027	0.032	0.03	0.036	0.035	0.014
	0.041	0.046	0.05	0.048	0.054	0.049	0.044
$S16$	0.03	0.035	0.04	0.037	0.043	0.038	0.034
	0.019	0.024	0.029	0.027	0.032	0.028	0.023
	0.034	0.034	0.037	0.035	0.036	0.036	0.034
$S17$	0.026	0.026	0.029	0.027	0.028	0.028	0.026
	0.017	0.018	0.021	0.019	0.02	0.02	0.017
	0.07	0.08	0.077	0.071	0.078	0.076	0.075
$S21$	0.052	0.063	0.059	0.053	0.06	0.059	0.058
	0.035	0.045	0.042	0.036	0.043	0.041	0.04
	0.046	0.048	0.048	0.051	0.054	0.054	0.044
$S22$	0.035	0.037	0.036	0.039	0.042	0.043	0.032
	0.023	0.025	0.025	0.028	0.031	0.031	0.021
	0.049	0.049	0.051	0.051	0.055	0.056	0.054
$S23$	0.037	0.037	0.039	0.038	0.043	0.043	0.042
	0.025	0.025	0.027	0.026	0.031	0.031	0.029
	0.033	0.035	0.039	0.037	0.042	0.043	0.031
$S31$	0.025	0.026	0.031	0.028	0.033	0.034	0.023
	0.016	0.018	0.022	0.02	0.025	0.026	0.014
	0.031	0.031	0.032	0.032	0.032	0.032	0.029
$S32$	0.024	0.024	0.025	0.025	0.025	0.025	0.022
	0.017	0.017	0.018	0.018	0.018	0.018	0.015
	0.019	0.02	0.021	0.02	0.022	0.021	0.02
$S33$	0.015	0.015	0.016	0.015	0.017	0.017	0.015
	0.01	0.011	0.012	0.011	0.012	0.012	0.01
	0.011	0.011	0.011	0.011	0.011	0.012	0.011
$S34$	0.008	0.008	0.008	0.008	0.009	0.009	0.008
	0.006	0.005	0.006	0.005	0.006	0.006	0.005
	0.002	0.003	0.003	0.002	0.003	0.003	0.003
$S35$	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	0.001	0.001	0.001	0.001	0.002	0.002	0.002
	0.003	0.003	0.003	0.003	0.003	0.003	0.003
$S36$	0.003	0.002	0.003	0.002	0.003	0.003	0.002
	0.002	0.002	0.002	0.002	0.002	0.002	0.002

Table 15: Positive and negative ideal solutions

	S11			S12			S13			S14		
v_j^+	0.189	0.154	0.12	0.197	0.16	0.123	0.109	0.087	0.065	0.052	0.04	0.029
v_j^-	0.139	0.104	0.069	0.147	0.11	0.073	0.091	0.069	0.047	0.042	0.03	0.019
	S15			S16			S17			S21		
v_j^+	0.036	0.025	0.014	0.041	0.03	0.019	0.034	0.026	0.017	0.07	0.052	0.035
v_j^-	0.058	0.047	0.036	0.054	0.043	0.032	0.037	0.029	0.021	0.08	0.063	0.045
	S22			S23			S31			S32		
v_j^+	0.044	0.032	0.021	0.049	0.037	0.025	0.043	0.034	0.026	0.032	0.025	0.018
v_j^-	0.054	0.043	0.031	0.056	0.043	0.031	0.031	0.023	0.014	0.029	0.022	0.015
	S33			S34			S35			S36		
v_j^+	0.022	0.017	0.012	0.011	0.008	0.005	0.002	0.002	0.001	0.003	0.002	0.002
v_j^-	0.019	0.015	0.01	0.012	0.009	0.006	0.003	0.002	0.002	0.003	0.003	0.002

Table 16: Calculations of d_j^+ and d_j^- for each option.

Options	d_j^+	d_j^+
Option 1 (before the second tunnel)	0.12	0.045
Option 2 (Akbar Joojeh)	0.089	0.054
Option 3 (Salavat Abad entrance)	0.05	0.098
Option 4 (after Razm Ara)	0.053	0.091
Option 5 (Kurkur turn 1)	0.052	0.118
Option 6 (Kurkur turn 2)	0.046	0.129
Option 7 (before the police inspection station)	0.128	0.047

Table 17: Calculated CL values.

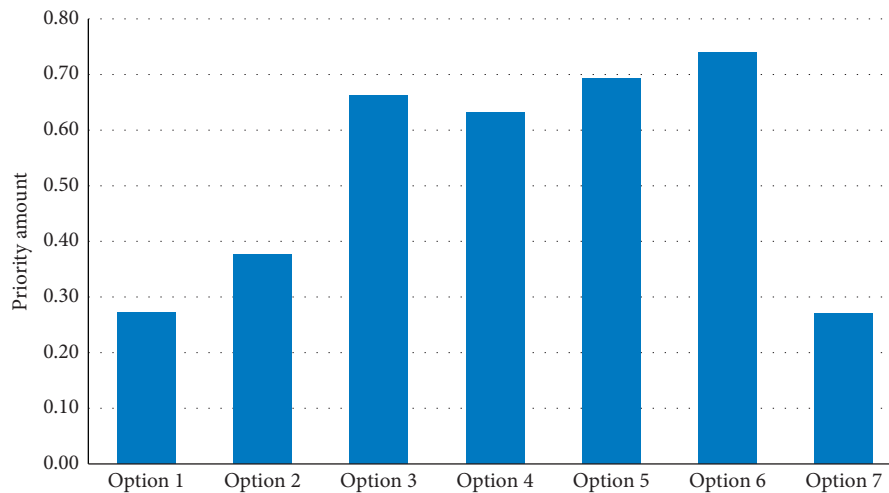| Options	d_j^+	d_j^+	CL	Final rank
Option 1 (before the second tunnel)	0.12	0.045	0.272	6
Option 2 (Akbar Joojeh)	0.089	0.054	0.377	5
Option 3 (Salavat Abad entrance)	0.05	0.098	0.663	3
Option 4 (after Razm Ara)	0.053	0.091	0.631	4
Option 5 (Kurkur turn 1)	0.052	0.118	0.693	2
Option 6 (Kurkur turn 2)	0.046	0.129	0.739	1
Option 7 (before the police inspection station)	0.128	0.047	0.27	7

Figure 10: Final priority of options.

4.8.6. Calculating the Ideal Solution. In this step, the relative proximity of each option to the ideal solution is calculated according to equation (10). *CL* value is between 0 and 1. The closer this value to 1, the closer the option to the ideal solution and the better the option. These values are presented in Table 17.

Therefore, according to the calculated values in Table 17 and results represented in Figure 10, it can be illustrated that

 (i) The best option was option 6 (Kurkur turn 2)

 (ii) Option 5 (Kurkur turn 1) was in the second place

 (iii) Option 3 (Salavat Abad entrance) was in the third place;

 (iv) Finally, option 7 (before the police inspection station) was the last priority

5. Conclusions

In this study, according to the importance of emergency escape ramps and identifying a suitable location to design these ramps, two common methods were presented from the analysis of criteria, with the importance of criteria explored by F-AHP, and finally, the appropriate location of the emergency escape ramp was proposed using F-TOPSIS. In the results of this research, important criteria were the percentage of longitudinal slope, longitudinal slope length, and vehicle design speed (as the technical criteria), which were significant more than economic criteria and other factors.

In the investigation of the main criteria, the results illustrated that the technical criteria (with 69% importance) were the most important factor influencing the location of the emergency escape ramps, and economic criteria and other factors with 19% and 11% importance, respectively, were effective after that, and in total, the following subcriteria were examined in the three main criteria:

 (i) The percentage of importance above 10% as the very important subcriteria:

 - Percentage of longitudinal slope with 19.7%
 - Longitudinal slope length with 18.9%
 - Vehicle design speed with 10.9%

 (ii) The percentage of importance 5% to 10% as the important subcriteria:

 - Cost of land acquisition with 8%
 - Horizontal curve radius with 5.8%
 - Operational cost with 5.6%
 - Construction cost with 5.4%
 - Physical development capability with 5.4%
 - Available right of way with 5.2%

 (iii) The percentage of importance 3% to 5% as intermediate subcriteria:

 - Accident statistics with 4.3%
 - Traffic level of service with 3.7%

 - Percentage of passing trucks with 3.2%

 (iv) The percentage of importance less than 3% as weak subcriteria

 - Average daily traffic with 2.2%
 - Access to public services with 1.2%
 - Conditions at the bottom of the longitudinal slope with 0.3%
 - Environmental effects with 0.3%

Among the proposed options, the four options 3, 4, 5, and 6 had the highest score, and option 6 (Kurkur turn (2)) was identified as the most priority location for the implementation of the emergency escape ramp. However, this does not mean that only one emergency escape ramp can be used on a given route, but if possible and depending on the importance, several emergency escape ramps can be used in the route.

The limitation of this study is the cost of acquisition within the Salavat Abad village and the area required to create an emergency escape ramp. Also, option 3 faces several administrative challenges due to its conflicts and economic costs, as it has to be developed within a residential area. For example, it intersects with infrastructure facilities such as water, gas, and telecommunication and fiber optic networks. Therefore, the cost of relocating or modifying infrastructure networks is one of the limitations of this research, especially for the implementation of the third option.

In future studies,

 (i) It is suggested that, after finding a suitable place for the emergency escape ramp, the design and construction of the ramp be investigated

 (ii) It is necessary to conduct other case studies with the indicators presented in this research in order to identify weaknesses and generalize them to spatial and environmental conditions

 (iii) To use the models applied in the coming years, the relative weights of the criteria can be modified during one-year periods by surveying experts

 (iv) It is suggested that the criteria of this model be evaluated by optimizing the structure of the questionnaire as well as by periodic reviews (for example, annual)

Data Availability

The data used to support the findings of this study are currently under embargo, while the research findings are commercialized. Requests for data, 3 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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