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Proposing a Model for Ranking Hotspots in Rural Roads Using a Multi-criteria Decision-making Method

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Abstract

Traffic safety, like many issues in transportation system, is affected by several factors. In Iran, usually the focus has been on the infrastructure engineering and it has been assumed that the crash rate can be reduced with only physical adjustments. Identifying and eliminating hotspots in recent years has been considered by the transport experts. However, effective criteria such as accident history, severity of the accident, traffic conditions for each point and etc. are not considered in the incident index. In this study, models are proposed for ranking the hotspots. Also, the criteria for considering a point as a hotspot and weight of each criterion are determined. To define the criteria for hotspots, statistical models are applied and multi-criteria decision making methods (TOPSIS) are implemented for developing the ranking model. Also, several points of the Iranshahr-Chabahar road were studied as a case study and the results of the proposed model were compared with the results of the model used by Iran road maintenance and transportation organization (RMTO). As would be observed, there is no significant difference between the results, which indicates that accident frequency plays a major role in both models.

1. Introduction

Traffic safety is one of the most prominent aspects of the transportation networks. This issue associated with fatality, injuries, financial losses, and delays, as direct costs and energy waste, missing workdays, and economic and psychological consequences, as some of the indirect costs. With this regard, many efforts have been made to decrease the number of accidents in rural and urban roads. Accordingly, road traffic hotspot identification is considered as one of the most effective approaches in improving the safety level of the road network which has already drawn experts' attention [1].

Accident hotspots must be prioritized based on their level of safety, for optimal assignment of the limited budgets. Thus, by immunizing and eliminating these points, regarding their priority, the related costs would be minimized [2]; however, it can be a challenging process. Because not only the stakeholders have to evaluate the effects of each countermeasure, but also they must take into account all political, social and environmental considerations.

Generally, the prioritization approaches can be classified into two different categories. In the first one, the prioritization is conducted based on technical and engineering considerations and based on the severity of the accidents. In this approach, several indicators, such as accident rate based on population or the amount of travel has been calculated, is used to score and subsequently prioritize hotspots [3]. Moreover, accident cost index is another indicator and its results can be used in the systematic evaluation of road safety; nonetheless, the calculation process is too complicated and needs a great deal of efforts. Five main components of the cost of road accidents are: 1- Cost of fatalities and permanent disabilities; 2- Cost of physical injuries (other than permanent disabilities) and cost of pain; 3- Sorrow, mental and psychological damage; 4- Cost of destroyed or damaged objects (which have a certain price in the market); 5- Cost of time spent and lost in road accident [4].

For the second category, the prioritization process is conducted by economic appraisal techniques (e.g. costs and benefits). Based on the economic evaluations, priority is given to the options with the highest rate of economic return. If sufficient information is not available to estimate the effects of countermeasures, the optimum option might be the one with the least costly plan [5]. In the economic evaluation

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of plans, methods such as the first year return rate, present net value, the ratio of the present net value to the present cost, the ratio of benefits to costs and the internal return rate are most widely used [6].

Considering a limited budget, there are several ways to prioritize road accident hotspots, among which ranking these points based on their significance seems to be the most appropriate approach.

In this paper, a number of methods for identifying the road accident hotspots are introduced first and further tests are presented to compare the methods. Accordingly, the hotspots in the studied route (Chabahar-Iranshahr) were evaluated using two different methods: Equalized Financial Loss Index and TOPSIS. In the final section, the results of these two approaches were compared and the results were interpreted.

2. Methodology

The dramatic increase of fatalities caused by road accidents in one hand and the effectiveness of the safety measures taken to mitigate road fatalities, on the other hand, has increased the need for extensive scientific and practical research. Accordingly, several studies have been conducted all around the world in relation to identifying and prioritizing the road accident hotspots [7]. Prioritization based on the risk assessment matrix applied in New Zealand or using the environmental and geometric characteristics of the road segments that have been used frequently in India are some examples of this approach over the world [8] & [9]. In Iran, till now, this process has been done merely based on the observations, experts' experiences and road accident statistics. Because not only a specific framework in the road accident hotspot identification has not been available, but also there is still no comprehensive road accident database being necessary for this process. Moreover, a point or section of the road changes from a normal to hotspot gradually. Therefore, the procedure for hotspot identification is a dynamic procedure and information for each point must be precise and complete. Also the evaluations must be frequent and up-to-date. To update the information for each point there must be a detailed and modern framework which depends on the available and new data. This research aims to propose a framework based on different effective measures for safety evaluations.

To address the study objectives, first, a summary of the research carried out in relation to the process of hotspot identification is discussed, which would help to consider all available contributing factors and valid modeling approaches. To investigate the accident data for rural roads, access to the road police database is essential. Accident data in this paper are provided by RMTO and relate to 2012 to 2015.

In this regard, by referring to RMTO, all available information from rural accidents including point coordinates, type of accidents, vehicles involved in the accident, hours and dates of the accident, and the number of Equivalent Property Damage Only (EPDO), injury and fatal accidents are collected.

Considering the extent of work and the lack of access to details, for gathering information about the other important variables, merely some specific road segments are selected as a case study. To obtain the technical and engineering specifications of the selected segments, the statistics of various variables along the road are determined by field inspections. Thus, a checklist is prepared to visit the points and then completed by the team at the site. Subsequently, the information would be applied to develop the model. In the next step, using the identified variables and the obtained database, according to the proposed model developed by TOPSIS method, the road accident hotspots are scored. To evaluate the effectiveness of the new approach, the results can be compared with the existing methods used by authorities.

2.1. Hotspot Identification Techniques

In this section, the most known hotspot identification techniques are discussed and their capacities will be evaluated in more details.

2.1.1. Accident Frequency

In this method, the points with the highest number of accidents are considered as the road accident hotspots. This approach is recommended when the other important variables such as traffic flow characteristics are not available. The average number of road accidents can be calculated using the Eq. (1) [10, 11]

$$f_{ave} = \frac{f_i}{n} \tag{1}$$

where f_i is the accident frequency and n shows the number of road segments.

2.1.2. Equalized Financial Loss Index

One of the most common methods for identifying road accident hotspots is to consider the accident consequences and provide an indicator for entering the severity of accidents in decision making and prioritization. In the method of Equalized Financial Loss Index, crashes are assigned in terms of severity (death, injury, damage). Thus, a mixed score is obtained for the frequency and severity of crashes for each location. This concept was introduced by Temmoir and Smith called "Safety Index" [12] that can be calculated from the Eq. (2)

$$EPDO = \alpha Fat + \beta Inj + PDO \tag{2}$$

where *Fat* is the number of fatal accident, Inj represents the number of injury accidents, and *EPDO* shows property damage only accidents. β and α are weight coefficients that can be calculated based the experts' experiences and relative average cost of fatal and injury accidents compared with *EPDO* accidents. In spite of all efforts have been made, various amounts of β and α have been obtained and there is still no consensus which one is the most accurate [13].

2.1.3. Regression Models

This approach involves a systematic analysis of input variables (such as geometric and traffic characteristics) by developing severity/ frequency prediction models or creation of a ration criterion. For instance, in creating an accident-frequency model, the goal is to describe both visible and invisible variations in the average number of accidents on specific sites [14]. The general form of these models is shown as Eq. (3).

$$Accident\ frequency = f_n(Dependent\ variables) \quad (3)$$

where dependent variables are geometric and traffic characteristics of a specific site. These models are also known as safety performance functions. Accordingly, different modeling approaches have been developed for accident frequency prediction based on statistics [15].

2.1.4. Empirical Bayes

Since the number of accidents is randomly fluctuating during the observation period, the prediction models cannot always provide an accurate estimation of the accident frequency, since the random variables have no effect on these models. To deal with this problem, the researchers have been evaluating the ways to control random fluctuations to predict the frequency of the accidents. One of the most capable approaches is the Empirical Bayesian method which has been frequently recommended by various researchers [16, 17]. To develop this model, first, the expected number of accidents in a specific site is calculated; subsequently, the estimated number of the accidents is combined with the observed number of the accidents to provide a more accurate estimation of road accident frequency.

$$EB = W \times \widehat{E}\,(y) + (1 - W) \times Count \quad (4)$$

$$W = \frac{1}{\left(1+\left(\widehat{E}\,(y)/_{K}\right)\right)} \quad (5)$$

where, C and $\widehat{E}\,(y)$ are the observed and predicted number of accident, respectively. K is the model parameter that can be estimated within the calibration process [18].

2.1.5. Severity-Rate of Accident

This method is derived from the combination of both accident severity and accident frequency approaches which are also known as Equivalent Property Damage Only (EPDO) technique. This measure can be calculated by dividing the equivalent number of EPDO accidents to the observed number of accidents in the field site. The steps involved in this process are discussed as follows:

a) The severity and location of all crashes are marked by GPS and subsequently coded.

b) Equivalent EPDO accident severity can be estimated by the Eq. (6)

$$E_i = a \times N_f \times b \times N_i + N_P \quad (6)$$

where, N_f, N_i, and N_P are the number of fatal, injury, and EPDO crashes, respectively and E_i is the road accident hotspots index. Moreover, a and b are the coefficients of the severity of the accident leading to death and injury, respectively.

c) The traffic volume of different sections is gathered and prepared.

d) Severity and rate of accident can be calculated using Average Daily Traffic (ADT), as follows:

$$\frac{(E_i)\times 10^6}{(ADT)\times(\text{study days})} \quad (7)$$

Indeed, this approach estimates the likelihood of an EPDO accident and compares the safety status of road segments and intersections. In this method, the severity-rate of the EPDO accidents is expressed in terms of 100 million vehicles [19, 20].

2.1.6. Frequency-severity

As mentioned, in the accident rate method, in addition to crash data, the traffic volume of daily passages is also required. However, in the cases where traffic volume data is not available, applying the frequency-severity method is recommended. In this method, for each segment or intersection, according to the accidents severity and frequency, a specific index (E_i) is determined which can be calculated from the following Equation. Then the hotspots are sorted and prioritized according to the value of this index.

$$E_i = 84 \times N_f + 3 \times N_i + N_p \quad (8)$$

where, N_f, N_i, and N_P are the number of fatal, injury, and EPDO crashes, respectively and a and b are the coefficients of severity of accident leading to death and injury, respectively. According to the investigations, if the traffic volume information is not available, the best way to prioritize the accident points is to use the Frequency-severity approach [19, 20].

2.2. TOPSIS

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision making (MCDM) method, which was originally developed by Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993 [21]. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. An assumption of TOPSIS is that the criteria are monotonically increasing or decreasing. Normalization is usually required as the parameters or criteria are often of incongruous dimensions in multi-criteria problems. Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion. This provides a more realistic form of modelling than non-compensatory methods, which include or exclude alternative solutions based on hard cut-offs [22]. Among the many compensatory approaches of MCDM, it is possible to consider a subgroup that involves costs and benefits aspects. One of them is the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method which was presented in, with reference to. This approach is employed for four main reasons:

a. TOPSIS logic is rational and understandable;

b. The computation processes are straightforward;

c. the concept permits the pursuit of the best alternatives for each criterion depicted in a simple mathematical form;

d. the importance weights are incorporated into the comparison procedures.

2.3. Case Study

In this section, the results obtained from the models are compared by considering a specific field site and developing the model. Accordingly, Iranshahr-Chabahar has been selected as the case study. The length of the road is 308 km and has 11 accident hotspots. The initial information was obtained based on the organizational database of the country and the technical information was collected in the field. It should be noted that the identification code of the points is based on the format approved by RTMO, so that the Latin letters represent the area, and the numbers relating to the approved code. The summarized information for each point is in Table 1.

Table 1. Characteristics of accident hotspots in the field site

Segment	Point Identification Code	Route name	Segment type
1	IRR16	Iranshahr-Chabahar	Intersection-Curve
2	IRR9	Iranshahr-Chabahar	Intersection-Curve
3	IRR5	Iranshahr-Chabahar	Curve
4	IRR4	Iranshahr-Chabahar	Bridge-Intersection-Curve
5	IRR8	Iranshahr-Chabahar	Intersection-Curve
6	IRR2	Iranshahr-Chabahar	Intersection-Curve
7	IRR12	Iranshahr-Chabahar	Bridge-Curve
8	IRR14	Iranshahr-Chabahar	Intersection-Curve
9	IRR3	Iranshahr-Chabahar	Bridge-Intersection-Curve
10	IRR6	Iranshahr-Chabahar	Intersection-Curve
11	IRR13	Iranshahr-Chabahar	Bridge-Intersection-Curve

In Iran, RMTO has announced a specific model for prioritizing the hotspots for its local departments. Based on this approach, first the route is divided into sections, then the accidents frequency is determined for each year. In this approach, the equivalent accident severity that represents the relative value of fatal, injury, and EPDO crashes is calculated from Eq. (9)

$$P = 5A + 3B + C \tag{9}$$

where, *A*, *B*, and *C* are the number of fatal, injury, and EPDO crashes, respectively. The results obtained by Eq. (9) are shown in Table 2.

Table 2. Scores for hotspots based on the equalized financial loss index

Segment	Point Identification Code	Score achieved based on model
1	IRR16	9
2	IRR9	13
3	IRR5	85
4	IRR4	23
5	IRR8	14
6	IRR2	42
7	IRR12	22
8	IRR14	23
9	IRR3	14
10	IRR6	15
11	IRR13	11

3. Results and Discussion

The first step in the modeling process is to identify the model parameters. Several factors are involved in identifying the likelihood of accident occurrence in a specific road segment. In the second step, the selected parameters are ranked based on both field inspections and predefined regulations. Based on the previous studies, the following parameters are involved in the modeling process

- Fatal accident frequency
- Injury accident frequency
- EPDO accident frequency

- Being in a sharp horizontal curve: based on the sharpness of the curve, the point is scored from zero to five, so that zero is assigned to a point that does not lie in the horizontal curve and 5 are assigned to a point that is located in the sharpest horizontal curve (minimum radius).
- Being in a sharp vertical curve: based on the sharpness of the curve, the point is scored from zero to five, so that zero is assigned to a point that does not lie in the vertical curve and 5 is assigned to a point that is located in the sharpest vertical curve (maximum gradient difference).
- Road width: If the road width is in accordance with the regulations, the score is zero, and if the low segment width is the main cause of the crash, the score is 5.
- Undesirable sight distance: if the minimum required stop distance is provided according to valid regulations, then the score is zero, and if the field defect is sufficient to cause the crash to occur, then the score is 5.
- Undesirable pavement condition: if the pavement condition is in accordance with valid regulations, it will be assigned a zero score and, if the pavement condition is in a near-deterioration condition, it will be scored 5.
- Horizontal marking condition: if the marking on the sides and in the middle of the road is in accordance with the valid regulations, then the score is zero, and if it does not have any signal; otherwise it would be equal to 5.
- Vertical signs condition: if the condition of the sign is complete according to the valid regulations, then the score is zero, and if signing is poor, then the score would be 5.
- Sever traffic conflicts: if there is no frequent and unsafe accesses in the point and right of way is properly obeyed, the score for the point is zero and if there are too much accesses and they are unsafe the score is 5.

It should be mentioned that first the correlation would be tested by statistical methods and the parameters would be selected after this procedure.

Subsequently, the decision matrix (weighting matrix) is developed for more than 300 incident points based on the results of field visits and assessment of the films and photos taken on the field as in Table 3.

In the next step, based on the anthropic technique and according to the formulations, the weight of each criterion is determined. Weights matrix is provided in Table 4.

Table 3. Decision-making matrix

Segment Code	number of fatal accident	Number of injury accidents	Number of EPDO accidents	Horizontal curve	Vertical curve	width	Sight distance	Pavement condition	horizontal marking	vertical signs	Traffic incidents
IRR16	0	3	0	3	0	1	2	0	0	1	0
IRR9	2	1	0	3	0	1	0	1	0	2	1.5
IRR5	7	16	2	2	3	1	3	0	2	2	0
IRR4	2	4	1	2	1	1	1	0	1	2.5	4
IRR8	2	1	1	0	0	1	3	1	2	3	4
IRR2	3	9	0	2	0	2	0	1.5	2	2.5	3
IRR12	3	9	0	4	1.5	2	4	0	0	4	0
IRR14	2	3	4	1.5	0	2	3	2	3	2	3
IRR3	2	1	1	1	3	1	3	2	3	4	5
IRR6	3	0	0	3	0	0	2.5	2.5	1	2.5	2.5
IRR13	1	2	0	2	1.5	2	2.5	1	2	3	4

Table 4. Weights of the criteria based on the anthropic technique

criterion	Number of fatal accident	Number of injury accidents	Number of EPDO accidents	Horizontal curve	Vertical curve	width	Sight distance	Pavement condition	horizontal marking	vertical signs	Traffic incidents
weights	0.0515	0.111	0.2178	0.0358	0.1966	0.0348	0.0558	0.1157	0.0861	0.0124	0.0825

Entropy is a major concept in physical science, social sciences, and information theory. It indicates the amount of uncertainty that exists from the expected content of an information message. The results indicate that according to the criterion of entropy weighing, the number of fatal accidents has the highest degree of certainty and the criterion of the status of horizontal signs has the highest uncertainty and it can also be stated that the reason for these differences is the different distribution of attributed weights [23].

In the next step, the normalized matrix is created based on the decision matrix, so that each value on the vector size is divided by the same index. The next step is to determine the ideal positive and negative option. In fact, the two virtual options created are the worst and the best options. The ideal positive and negative options are calculated and presented for different criteria and are according to the Table 5.

In the next step, the distance between each option and the positive and negative ideal option is measured. In the final step, for each option, the amount of closeness to the ideal solution is calculated and then prioritization process is conducted to the ideal option according to the Table 6.

As mentioned, the method of scoring the points is based on how close they are to the ideal options and the criterion of the closeness coefficient represents the same issue. In Table 7, a comparison between two prioritization approaches is provided.

Table 5. Optimized solutions

Optimized options	number of fatal accident	Number of injury accidents	Number of EPDO accidents	Horizontal curve	Vertical curve	width	Sight distance	Pavement condition	horizontal marking	vertical signs	Traffic incidents
+	0.0366	0.0829	0.1817	0.0181	0.1217	0.0148	0.0268	0.0655	0.043	0.0055	0.0414
-	0	0	0	0	0	0	0	0	0	0.0014	0

Table 6. Prioritization of the options

Segment	Coefficient of closeness
IRR5	0.5988
IRR14	0.5796
IRR3	0.4902
IRR4	0.2869
IRR12	0.2856
IRR13	0.2834
IRR8	0.2608
IRR2	0.2498
IRR6	0.2397
IRR9	0.1251
IRR16	0.0937

Table 7. Comparison between two prioritization approaches

Equalized Financial Loss Index		TOPSIS	
Identification code	Priorities	Identification code	Priorities
IRR5	1	IRR5	1
IRR2	2	IRR14	2
IRR4	3	IRR3	3
IRR14	4	IRR4	4
IRR12	5	IRR12	5
IRR6	6	IRR13	6
IRR8	7	IRR8	7
IRR3	8	IRR2	8
IRR9	9	IRR6	9
IRR13	10	IRR9	10
IRR16	11	IRR16	11

In this section, the results of both models are examined and compared. As can be seen, there is a significant similarity between two methods. This is due to the fact that the number of accidents still has a significant weight; because the maximum degree of certainty by the entropy method is allocated to the number of fatal, injury, and EPDO accidents. The reason is that the role of the accidents frequency in determining the accident hotspots is undeniable. Therefore, there is no significant difference between these two approaches.

Another advantage of the new method is that, in addition to the accidents frequency, the criteria that are potentially effective in the accidents occurrence are also involved in prioritizing the accident hotspots. Furthermore, the traditional approach has several other drawbacks that cannot be disregarded. For instance, not only it needs an extra time and cost for the field visit, but also personal judgments are involved in the process.

4. Conclusion

In this research, the efforts have been made to provide a model for scoring and prioritizing accident hotspots. To address this goal, until now, different modeling techniques have been used. Among them, regression models, Equalized Financial Loss Index, Empirical Bayesian, Severity-Rate, and frequency-severity have drawn the most attention which are briefly discussed in the previous sections. Generally, this research seeks to propose an effective model for hotspot prioritization. To evaluate the capabilities of the new approach in pursuing the predefined objectives, the results are compared with the traditional approach which has been frequently used by RMTO. With this regard, Iranshahr-Chabahar route was selected as the case study and subsequently evaluated in more details. To develop the model for scoring accident hotspots, it is first necessary to determine some specific criteria. TOPSIS method is used to rank the hotspots so that the rating matrix is provided based on the experts opinion, evaluation of the films and photos obtained from field site and their compliance with valid regulations. Also, weighing the criteria was done using entropy method as a statistical technique. Finally, by comparing the results of the proposed model with the model of equalized financial loss index, it was concluded that the criterion of the number of accidents is the main factor in the accident hotspot prioritization. Although the impact of other criteria is low, there is still a need for other criteria to be considered in the modeling process. Also, it would have been advisable to use other powerful methods like AHP-fuzzy in the same priority setting for the upcoming studies.

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