Identification of Road Critical Segments Using Wavelet Theory and Multi-Criteria Decision-Making Method

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Abstract

The identification of road accidents prone locations with their prioritization plays an important role in managing appropriate allocation of budget and resources to improve roads safety. Therefore, this research shows a comprehensive model for segmentation and prioritization of roads. The segmentation model, by converting the accident data into analytical signals, and providing a dynamic model is based on the wavelet transform mathematical theory, and obtains the length of the road critical segments according to the accident intensity and ultimately, these segments are prioritized based on the Multi Criteria Decision Making method. In this paper, a case study was carried out on one of the Khoy-Ivoghli road of West Azarbaijan, with a length of 30 km, and seven segments with different lengths were obtained where segments with indices of 1, 2, 3, 6, 7 with a limited length of the road were referred to as minor accident prone segments and segments with indices 4 and 5 were called major accident prone segments. Also, prioritizing the accident prone segments with Expert Choice software was obtained equal to $A_5 > A_4 > A_7 > A_6 > A_1 > A_3 > A_2$. As a result, the segment A_5, at a distance of 6.25 to 19.75 from the beginning of the road, is at the higher priority, and the A_2 segment, which is located at a distance of 9.5 to 10.5 from the beginning of the road, has a lower priority in improving the safety.

Keywords: Toad accidents, Segmentation, Wavelet transform, Multi-Criteria decision-making method

1. INTRODUCTION

Road accidents have injured every year many people and are one of the most important causes of death in the world, especially in Iran. The serious casualties and injuries caused by road accidents cause considerable loss of national resources, and concern and affection of the family of the accident victims. According to the World Health Organization's latest report in 2015, the world's 1.25 million people die annually due to road accidents, and about 50 million people are injured and disabled (Boroujerdiyan, 2014). Evaluation of transport safety has been a concern of road

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authorities for many years. Human, road, environment and vehicle characteristics are the main factors influencing the safety level of road networks (Ogden, 1996). According to statistics from the National Forensic Organization of Iran and the Ministry of Transportation and Road Administration, in 2016, 15932 people were killed and 333071 injured and 10427 died due to road accidents. Because of the high number of road accidents, there is a growing need to reduce the incidences. One of the important factors in road accidents is the existence of critical segments in arterial transport roads, which investments should be done in order to increase safety and improve these points (Boroujerdiyan, 2014). Due to the growth in traffic accidents and public health threats, the United Nations (UN) has named the Decade 2011-2020 as the “Action for Road Safety”. Even some countries, such as Sweden and some US states, introducing plans to reduce the growth of traffic accidents, have implemented the "Zero Vision Program" aimed at designing roads with the lowest risks (Rouhi and Hasanzadeh Esfahani, 2015). Making safe roads for all users requires time and facilities, However there is a limited budget, time and facilities, as well as lack of supporter organizations, identifying accident prone segments and prioritizing these segments is one of the appropriate management solutions to relatively achieve goals of safe roads (Boroujerdiyan, 2014). In fact, by improvement and maintenance of some of the points and segments and allocating limited resources available to some projects, the basis for quick completion of these projects is provided, while remaining points are not ignored and prioritized (Kazemi and Zooghi, 2011). In this study, a new dynamic segmentation approach is used to identify accident segments, one of the advantages of which is that the road incidence is defined on the basis of segments, not based on road points and Multi-Criteria Decision Making (MCDM) methods are used to prioritize accident-prone segments. In the dynamic segmentation model, the length of the accidental segment is obtained by converting the accidental data into analytical signals and presenting a dynamic model based on the wavelet transformation mathematical theory. In commonly used methods for segmentation, due to the constant assumption of the length of the segments studied, there are many problems with the process of identifying the accident-prone segments, among the most important of which is the failure to identify some accidental segments due to the lack of incompatibility of the length introduced by these methods with the actual length of the accidental segment or the lack of placement of the location of the accidents occurring along a segment (Boroujerdiyan, 2014). The prioritization model is implemented using the AHP method and Expert Choice software. Therefore, the main objective of the research is to provide a framework for achieving a comprehensive model for road segmentation and a model for prioritizing the accident prone segments of accidents. One of the practical objectives of this research is to identify high risk and accidental segments of one of the arterial roads of West Azerbaijan province in Iran. Therefore, the modelling of the research process can be useful for determining the accidents on other roads. Finally, the goal of this paper is to achieve 100% safe roads with a high quality level and most importantly without any accident.

2. RESEARCH BACKGROUND

So far, some researchers have attempted to estimate accident models with a road segmentation approach, but most of them simply considered road segments with fixed length or between two main intersections. Abdel-Aty and Radwan (2000) modeled the road with homogeneous characteristics in terms of traffic flow and geometric conditions (horizontal curvature, shoulder width and Middle Island, line width, etc.), segmentation and accidents (Abdel-Aty and Radwan, 2000). Mahmood Saffarzadeh et al. (2009) used group decision-making methods to identify effective criteria to prioritize accidental segments and the importance of each of them (Eliasy et al., 2015). Cafiso et al. (2010) also developed a comprehensive segmentation method based on a combination of at-risk exposure, geometric conditions, compatibility, and conceptual variables related to safety performance and modeled the accidents (Cafiso et al., 2010). Anastasopoulos et al. (2008) in their research examined that the pavement condition pavement condition, roadway geometrics and traffic characteristics significantly affect vehicle accident rates. In their research, they divided the road to homogeneous segments according to the Present Serviceability Rating of pavement, in which the ranking has been conducted according to the AASHTO method (Anastasopoulos et al., 2008). In a research, Medury and Grembek (2016) segmented the road with homogeneous traffic and conditional features and used the SW moving window method with fixed-length. One segment in this method has a fixed window length which has the maximum number of accidents (Medury and Grembek, 2016). Tabi Amponsah (2015) also used the AHP methodology and Expert Choice software to prioritize implementation of road projects (Tabi Amponsah, 2015).

2.1 MEASUREMENT AND EVALUUTION OF EXISTTNG SEGMENTATION METHODS

The methods for segmentation can be divided into two categories:

a. Static segmentation: static segmentation methods include all methods in which the length of the segment is constant and the accident-prone segments are identified by segmentation of the road to the segments with specified lengths after counting the number of accidents occurring in the segments considering the accident-prone definition.

b. Floating segmentation: From the beginning of the road, depending on the length of the supposed accident-prone segment, a model with a fixed length equal to that length is made, and then the model is moved along the road with fixed specified steps, and the number of accidents is calculated in these segments.

Four of the basic drawbacks of static segmentation methods are (Boroujerdian et al., 2014):

1. Possible removal of areas of the road with high accident density

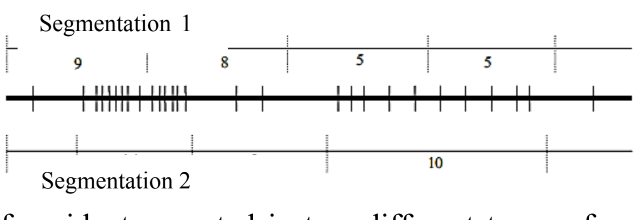

Figure 1. The number of accidents counted in two different types of segmentations (Boroujerdian et al., 2014)

As seen in Figure1, the number of accidents of none of the segments in segmentation 1 has exceeded 10, but by changing the type of segmentation (based on the density of accidents), segments with numbers greater than 10 are also seen.

2. Failure to understand the specific result of the distribution of accidents:

when the number of accidents occurring within a range exceeds a certain limit, it can indicate a problem in that range; for example, curb Radius Reduction in a limited section of the road or inappropriate viewing distance in a specified area, but if the accident position is distributed in a long distance of the road, the accidents may be dispersed due to human errors depending on the circumstances, or due to geometric problems along the road, such as the lack of enough width or shoulder width.

1. Incapability of identification o f segments at different scales:

if there are local and technical faults in construction and design of a certain length roads, the existing methods are not able to identify it.

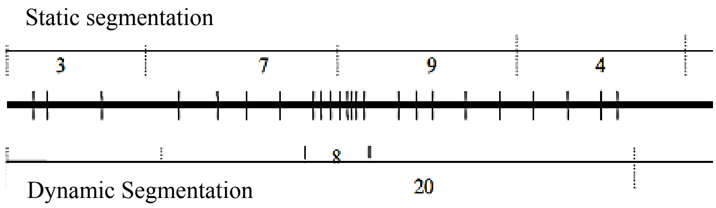

Figure 2. Number of accidents counted in two static and dynamic segmentations (Boroujerdian et al., 2014)

As Figure 2 shows, dynamic segmentation has been able to identify a segment with 8 accidents over the length of the segment, but in static segmentation, the accidents of the range have been broken up into two segments and the probability of failure to identify it has been increased.

4. Inconsistency of the length of an accident-prone segment with the length specified in the segmentation:

If the length of the accidental segment is actually greater or less than the length of each segment, then the appropriate length cannot be detected in the existing methods. Figure 3 suggests that the length of the accident-prone segment should be determined according to the extent of the cause of the accident along the road, and the constant assumption of the length of the segments at the identification stage may cause error and deviation in the process of identifying the accidental segments.

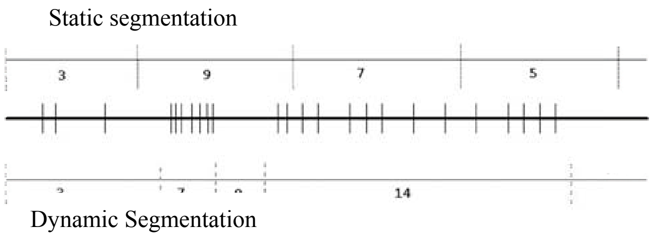

Figure 3. Number of accidents counted in two static and dynamic segmentations (Boroujerdian et al., 2014)

As shown in Figure 3, for example, in a dynamic segmentation, the segment with 7 accidents has a length corresponding to its own cause, while in the static segmentation, a specified length has not been determined for the length.

c. Dynamic segmentation: This method is used to improve the static segmentation using a mathematical model of the wavelet theory which, in accordance with the arrangement of accidents along the roads, identifies the actual length of the accident-prone segments.

2.2 *The MATHEMATICAL PRINCIPLE OF WAVELET THEORY*

One of the mathematical methods is used today to dynamically analyse the information is the wavelet transform analytical method to process the signal. Signal processing is carried out based on wavelet theory to obtain information such as determining the dominant frequency and the time of occurrence, frequency content with the knowledge of their occurrence time, identification and removal of the scattered data of the process, the process energy distribution at different frequencies according to time, etc. The wavelet transform is defined according to Equation (1) (Mallet, 1998):

$$w_{\psi} f(a,b) = < f, \psi_{a,b} > = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} f(t).\psi^{*}(\frac{t-b}{a})dt \tag{1}$$

$\Psi_{a,b}$ is the transferred wavelet Ψ as b and scaled as a. Transmission (b) refers to the process that the window displaces over the signal. Obviously, this expression refers to time information in the transformation space, thus determining the window displacement. The scale (a) in wavelet analysis is similar to that used in maps (Mallet, 1998). If the wavelet transform coefficients for continuous bs and as are calculated, it is called the continuous wavelet transform (CWT). The continuous wavelet transform is defined as Equation (2) (Mallet, 1998). In this study, continuous wavelet transform is used according to Equation (2).

$$CWT_{x}^{\psi}(\tau,s) = \psi_{x}^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}} \int x(t).\psi^{*}(\frac{t-s}{s})dt \tag{2}$$

In the above relation, the transformed signal is a function of two variables, τ and S, which are transmission and scale parameters, respectively.

In this study, the Mexican hat wavelet family has been used. This wavelet is from the first group of wavelets, i.e., raw wavelets. Its good feature is that it is abundant, simple and clear. But its analysis is non-orthogonal uncompromising. A scale function has not been attributed to this wavelet. Mexican hat wavelet, is the second derivative of Gaussian function. The Mexican hat wavelet function relationship is defined according to Equation (3) (Mallet, 1998), and Figure 4 shows the Mexican hat wavelet functions.

$$CWT_{x}^{\psi}(\tau,s) = \psi_{x}^{\psi}(\tau,s) = \frac{1}{\sqrt{|s|}} \int x(t).\psi^{*}(\frac{t-s}{s})dt \tag{3}$$

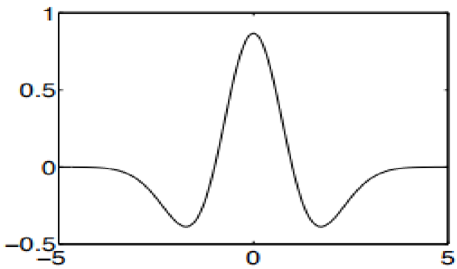

Figure 4. Mexican hat wavelet (Mallet, 1998)

3. RESEARCH METHODOLOGY

In this research, after determining the location of accidents along the road based on the accidents data recorded by the police and according to the accidents data and the accident intensity, the road sections are segmented and identified based on the potential accident-prone. In this method, by simulating the accidents data to the signals that can be analyzed by the mathematical theory of wavelet transformation, suitable models are used for their analysis. The method proposed in this research is dynamic segmentation using wavelet theory, which is a new method for signal analysis, and has not many of the drawbacks and limitations of previous methods (Boroujerdiyan, 2014). Then, using the AHP based on approach Expert Choice software, the accidental segments are prioritized (Saaty, 1996).

3.1 SEGMENTATION USING WAVELET TRANSFORM

The identification flowchart of the accident-prone segments using the wavelet theory is represented as Figure 5 (Boroujerdiyan, 2014).

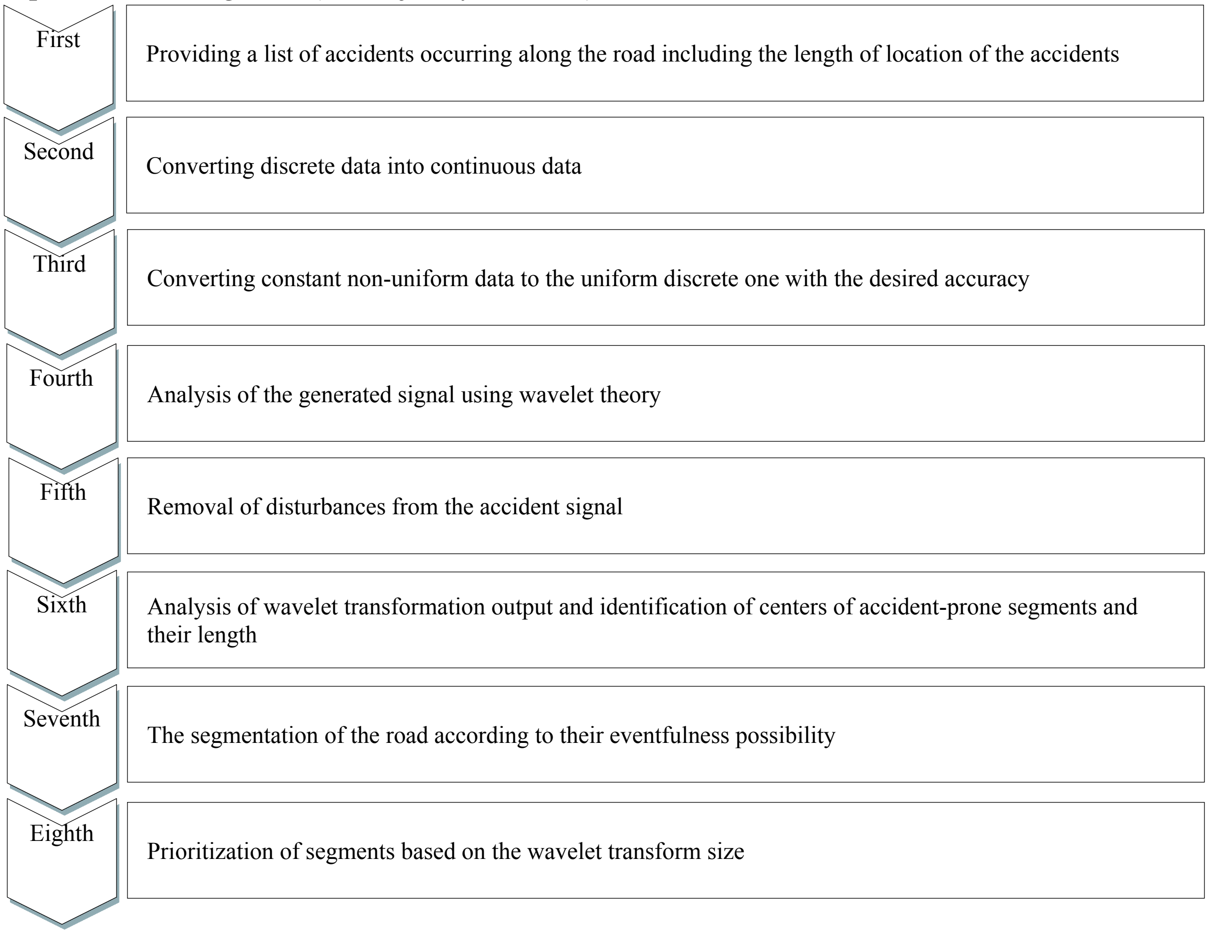

Figure 5. Identification flowchart of accidental segments using wavelet theory (Boroujerdiyan, 2014).

3.2 MODELLING AND SOLVING STEPS

1. conversion of accidents data to a processable signal:

It is one of the first stages of modeling. After collecting data as converting non-uniform data into uniform data, the main stages of the procedure begin. After that the linear kernel function is used to estimate the data and convert the data to the continuous signal. One of the reasons for this is the coordination of the linear function with the kernel function and its coordination with the accident influence domain function (Boroujerdiyan, 2014).

2. Analysis of signal with wavelet theory:

For analysis of the signal using wavelet theory, the Mexican hat wavelet has been used.

The outputs from the wavelet analysis are analyzed by MATLAB software and investigated, and based on the analysis outputs, the centers of the accident-prone segments as well as the length of the segments are specified. Using the Mexican hat window allows the analyst to identify the center of the accident-prone segment and its influence area. In this method, the locations which are identified as peaks in the wavelet theory analysis diagram, demonstrate the same center of the accident-prone segments. Figure 6 shows the scale size graph in the Mexican hat window.

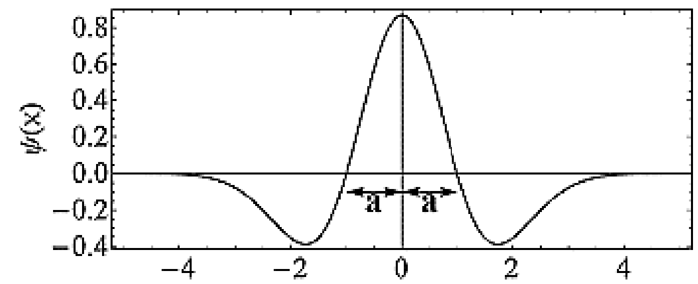

Figure 6. Meteorite hat window diagram and scale size (Boroujerdiyan, 2014)

Since the amount of accident data is always positive, so the maximum size of the wavelet transform occurs on a scale where the information is located in the positive range of the wavelet window. Thus, by doubling the size scale of the wavelet transform of the center of the accident-prone segment, the length of this segment can be detected. By moving the selected analysis window as a wavelet and changing its scale at any point, and plotting the magnitude of the product of the signal in the wavelet window with different scales, it is possible to identify the segments of the road which have been the location of occurrence of a number of accidents due to some factors (Boroujerdiyan, 2014).

3.3 SOLVING THE PRESENTED MODEL WITH A REAL EXAMPLE

In order to assess proposed research models properly, using the actual example in this section, the proposed method is evaluated. In this study, among all the major transportation roads in West Azarbaijan province in Iran, the Khoy-Ivoghli road has been studied. The length of this road is 30 kilometers. Visual pattern of the accidents data recorded on the Khoy-Ivoghli road is shown in Figure 7. In this figure, the horizontal axis represents the length of the road in kilometers and the vertical axis represents the number of accidents.

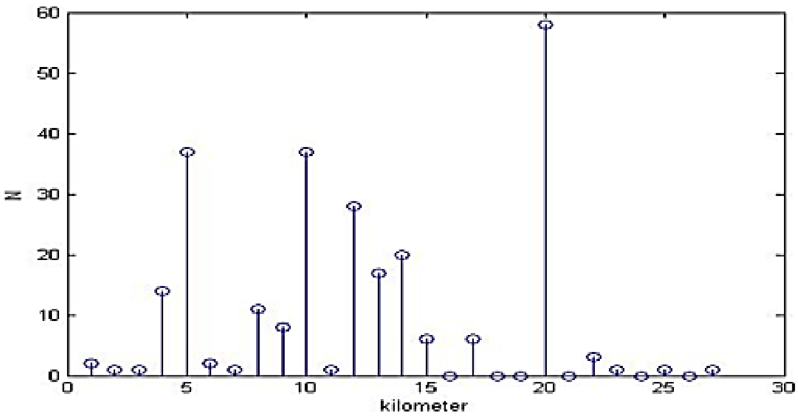

Figure 7. Visual pattern of the accidents data recorded on the Khoy-Ivoghli road

Figure8 is the result of the output of signal processing of the sample accident using a wavelet transform. In this figure, the horizontal axis represents the length of the road and the vertical axis represents the wavelet scale. X represents a selected point in this figure representing the position of the point along the road, Y represents the scale in which the wavelet transform size at that point is maximum and the level line passing through it represents the size of the wavelet transform at that point. As can be seen, wherever an accident is recorded in Figure 7, its effect can be seen in Figure 8. The centers of the accident-prone segments are the peaks of level lines, and the scale size of the peaks shows the length of the accident-prone segments.

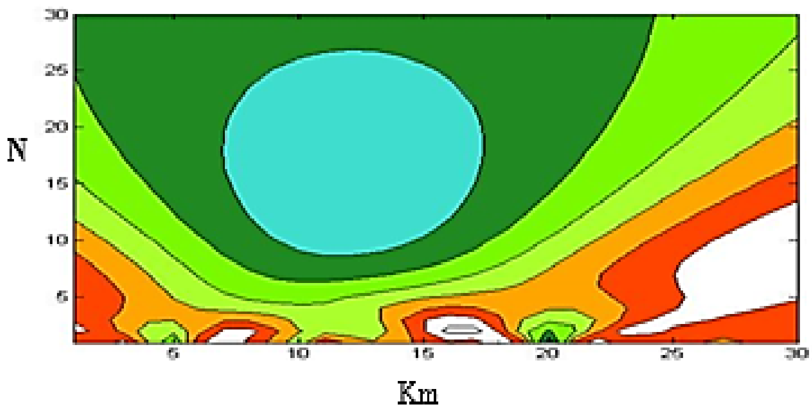

Figure 8. Output of the unrefined wavelet transform of Khoy-Ivoghli road

De-Noising: Since accidents occur along the road in a single and scattered way and do not indicate the presence of a specific accident factor in that area, therefore the model should be able to eliminate such scattered data from the total accident rate and can reduce the analysis error. One of the capabilities of the model is the elimination of disturbances in the data. To remove disturbances, the Daubecheis 8 wavelet family has been used. Figure 9 shows the output of the refined wavelet transform.

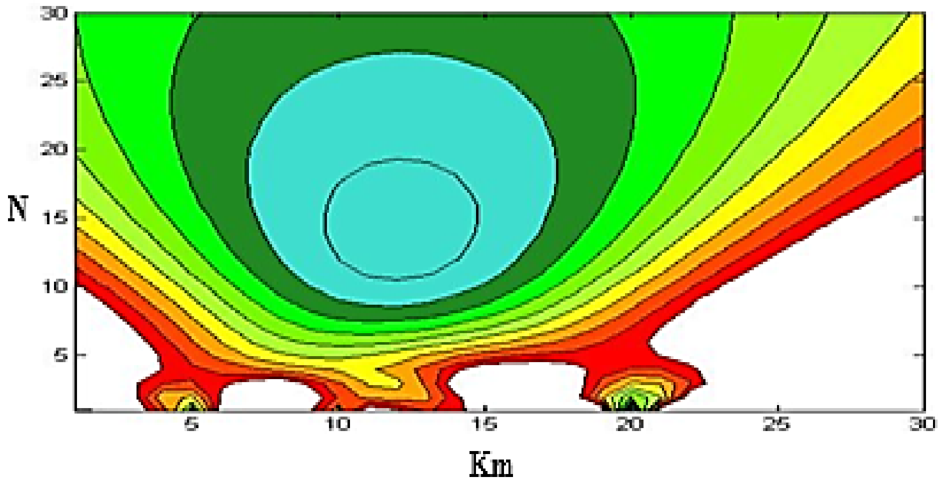

Figure 9. Output of the refined wavelet transform of the Khoy-Ivoghli road

Road Segmentation: In Figure 10, the road is segmented by using the refined output of the wavelet transform from the MATLAB software. At this stage, the minor and major accident-prone segments are determined using modified wavelet transform procedure.

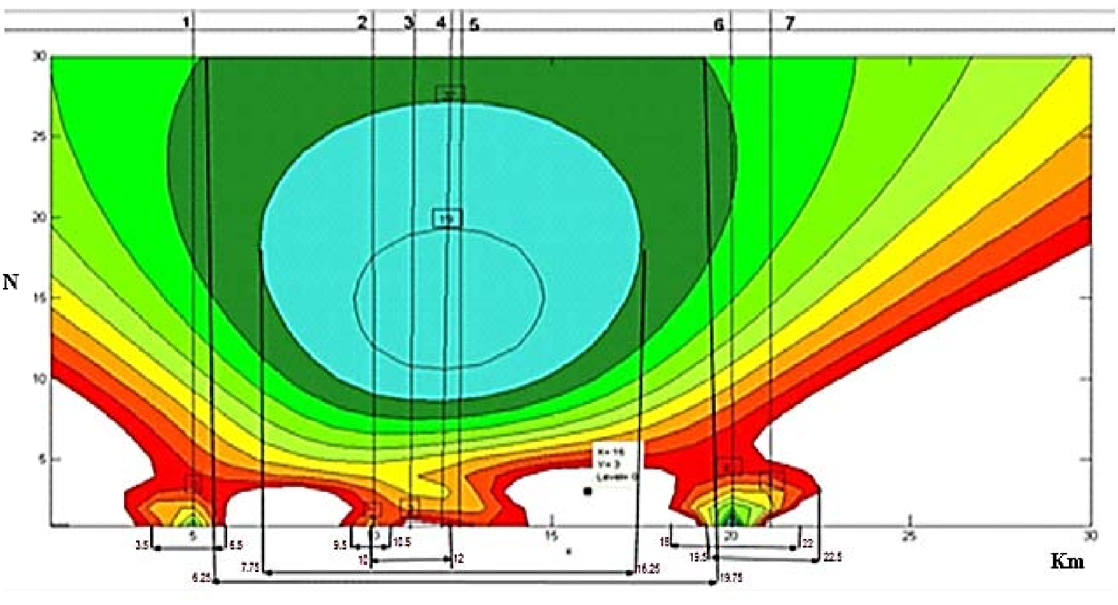

Figure 10. Segmentation of the Khoy-Ivoghli road

As already mentioned, the centers of the accidental segments are the same as the peaks of the level lines and the scale size of the peaks indicates the length of the accidental segments. Thus, according to Figure 10, this road was divided into seven segments of different lengths, and the results are presented in Table (1).

Table 1: Segmentation results of the Khoy - Ivoghli road

Segment number	*Length*	*Kilometers (from km ... to km ...)*
1	3	3.5 - 6.5
2	1	9.5 - 10.5
3	2	10 - 12
4	8.5	7.75 - 16.25
5	13.5	6.25 - 19.75
6	4	18 - 22
7	3	19.5 - 22.5

Segments were ranged from 1 to 7, which have identified a limited length of the road as an accidental segment, are called minor accident-prone segments and segments with 4 and 5 indices are called major accident-prone segments. The minimum length of a segment that can be identified by this method is the same length of sampling step that is defined in many minor accident-prone segments and is visible in Figure 10.

3.4 PRIORITIZATION OF THE KHOY-IVOGHLI ROAD USING MULTI-CRITERIA DECISION MAKING METHOD

considering the factors affecting their occurrence and identifying and prioritizing the critical segments. AHP is one of the most well-known methods of multi-criteria decision-making methods based on the paired comparisons, and presents decision-making processes in a hierarchical or network structure, and can determine the prioritization of choices introduced in decision making which is usually performed using the Expert Choice software (Saaty, 1996). Mathematically, AHP uses pair-wise comparisons to systematically scale the items. It calculates the eigenvalues of the Relative Weight Matrix (RWM), and determines the relative weights by determining the eigenvector (Agarwal et al., 2013). In AHP, the relative weight matrix of the criteria is obtained using the results of the questionnaires:

The relative weight of the criteria is defined using the results of the questionnaires according to Equation 4, which is:

$$w_{n\times 1} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{matrix} R \\ E \\ H \end{matrix} \begin{bmatrix} 0.309 \\ 0.137 \\ 0.555 \end{bmatrix} \tag{4}$$

These criteria are the same as the factors affecting the occurrence of accidents. 1. Road factor (R). 2. Environmental factor (E) 3. Human factor (H) as shown in Figure 11.

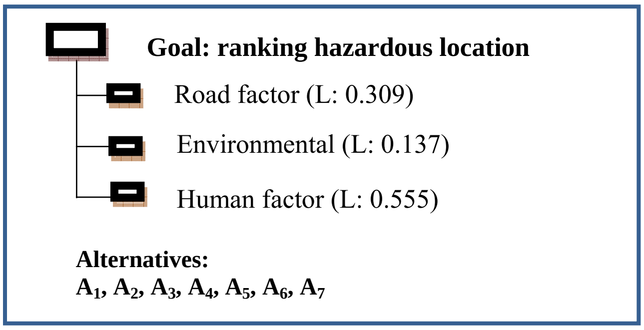

Figure 11. The factors affecting the occurrence of accidents

The EXPERT CHOICE Software inputs are as follows:

Goal: Ranking accident-prone segments

Criteria: Factors involved in the occurrence of accidents: Road factor, Environmental factor, Human factor

Alternatives: Segments are entered as alternatives.

An: The accident prone segment

Figure 12 shows the hierarchical process in AHP, which is called the decision tree, which in fact represents a graphical decision-making strategy. First, the purpose of the decision is written in this tree, and then the factors affecting decision making are shown from the top down in the different levels. The final level offers decision alternative. By inserting the input data from Table 1 and inputs from Figure 11, the final results of the analysis and prioritization of the accident prone segments are obtained. Figure 13 shows the analytical results of 7 accident prone segments.

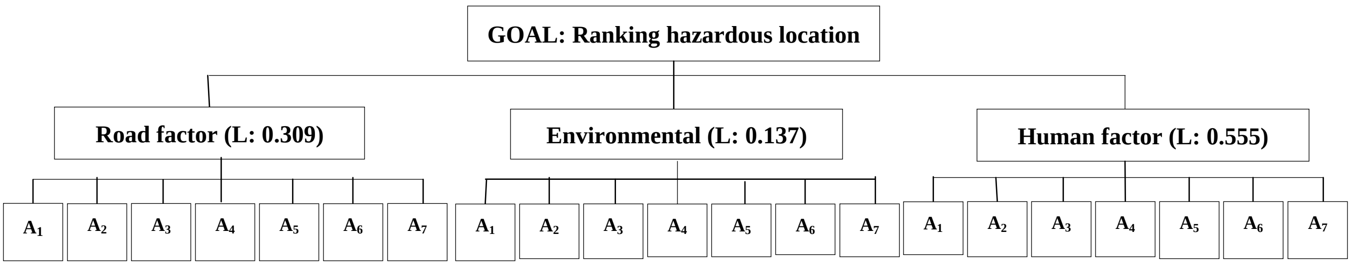

Figure 12. Hierarchical process for the EXPERT CHOICE software.

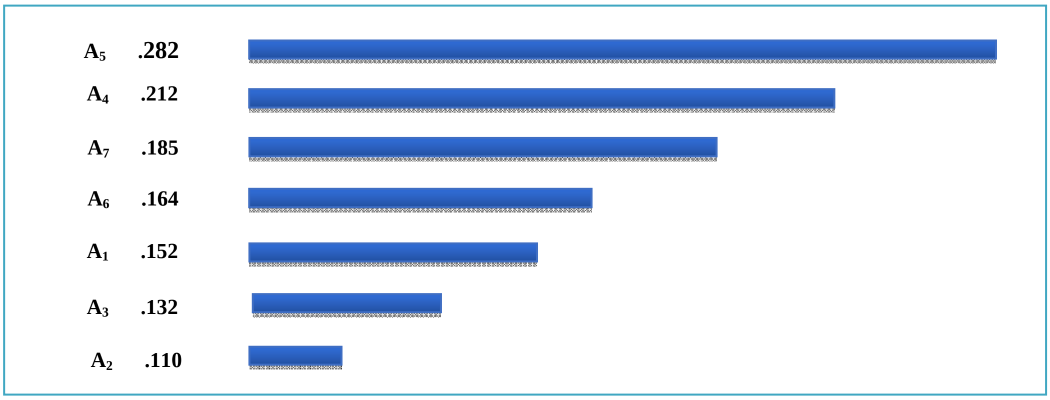

Figure 13. Ranking analytical results from 7 accident prone segments

According to Figure 13, the ranking results of accident prone segments from major to minimum priority are obtained. Thus, result is A5 > A4 > A7 > A6 > A1 > A3 > A2 . According to the results, the segment A5, which is placed in the distance 6.25 to 19.75 from the beginning of the road, has the higher priority, and the segment A2, which is in the distance 9.5 to 10.5 from the beginning of the road, is in the lower priority to improve the safety condition. Therefore, the next segments are also prioritized.

4. CONCLUSIONS

Due to the high cost of removing accident prone segments of roads, it is important to identify their exact length. According to research carried out in the paper, it was found that previous researches for segmentation are incapable of identifying the length of a accident-prone segment in accordance with occurred accidents, and therefore, if the length of the accident-prone segment is smaller or larger than its segmentation step, this length is not identifiable accurately. The results of the study are expressed as follows:

1. The length of the accidental segments can be determined in the order of accidents along the road, as well as the identification of accident-prone segments with shorter lengths along the accident-prone segments with dynamic segmentation method.
2. Identification of accidental segments by dynamic segmentation and prioritization can be obtained by MCDM method.
3. The wavelet transform signal analysis method can be used in dynamic segmentation method.
4. In the current research, in which a case study was carried out on the 30-kilometer Khoy-Ivoghli road, 7 segments of different lengths were obtained, where segments with 1, 2, 3, 6 and 7 indices with a specified length of the road were identified as the minor accident-prone segments and segments with 4 and 5 indexes as the major accident-prone segments. Also, the priority of the accident-prone segments with the help of AHP method was $A_5 > A_4 > A_7 > A_6 > A_1 > A_3 > A_2$, respectively. As a result, the segment A_5, which is placed in the distance 6.25 to 19.75 from the beginning of the road, has a higher priory than other segments to improve safety. In this way, accident-prone segments were identified and prioritized with proposed methods.

References

Abdel-Aty, M. A.; and Radwan, A. E. (2000) "Modeling traffic accident occurrence and involvement", *Journal of Accident Analysis and Prevention* 32, pp. 633–642.

Agarwal. P. K.; Patil. P. K.; Mehar. R. A. (2013) "Methodology for Ranking Road Safety Hazardous Locations Using Analytical Hierarchy Process", *in Proc. Of the 2nd Conference of Transportation Research Group of India (2nd CTRG). Elsevier: Procedia - Social and Behavioral Sciences* 104 :1030 – 1037.

Anastasopoulos, P. C.; Tarko, A. P. and Mannering, F. L. (2008) "Tobit analysis of vehicle accident rates on interstate highways", *Journal of Accident Analysis and Prevention*, 40, pp. 768–775.

Boroujerdian, A.M.; Saffarzadeh, M.; Yousefi, H. (2014) "A model to identify high crash road segments with the dynamic segmentation method", Journal *of Accident Analysis and Prevention 73*, pp. 274–287.

Boroujerdiyan, A. (2014) "Providing Road Safety Assessment Model Based on the dynamic segmentation and causal priority", PhD thesis, Tarbiat Modares University. https://ganj.irandoc.ac.ir/articles/511216.

Cafiso, S., DiGraziano, A., DiSilvestro,G., La Cava, G., and Perseus, B. (2010)" Development of comprehensive accident models for two-lane rural highways using exposure, geometry consistency and context variables", *Journal of Accident Analysis and Prevention* 42, pp. 1072–1079.

Eliasy, M., Boroujerdiyan, A., Safarzadeh, M., Jannati, H., and Mazaheri, M. (2015) " Presentation a model for risk estimation of accidental segment And comparing it with the accident rate (Case study: Hamadan axis to Malayer) ", *in Proc. of the 15th International Conference on Transportation and Traffic, Tehran.*

Kazemi, A.; Zooghi, H. (2011) "Identification and prioritization of accidental points On Suburban Roads and Presentation Software" , *in Proc. of the 11th International Conference on Transport and Traffic, Tehran.*

Mallet, S. (1999) " A Wavelet Tour of Signal Processing", Academic Press.

Medury, A., Grembek, O. (2016) " Dynamic programming-based hot spot identification approach for pedestrian crashes", *Journal of Accident Analysis and Prevention* 93, pp.198–206.

Ogden, K.W. (1996) "*Safer Roads: A Guide to Road Safety Engineering"*, Monash University: Institute of Transport Studies.

Rouhi, A.; Hasanzadeh Esfahani, M. (2015) "Providing an Optimal Method for Identifying and Detecting Accidental Points", *in Proc. of the 14th International Transport and Traffic Conference, Tehran.*

Saaty, T. L. (1996)“ *The Analytic Hierarchy process”*, McGraw Hill, New York.

Tabi Amponsah, C. (2015) “An integrated approach for prioritizing road projects for implementation using AHP*”*, *International Business and Entrepreneurship Development*, 8(2), pp. 128-143.