IJTE, Vol. 10, No. 1, Summer 2022, pp. 865-875

Research Paper

Identification Methods of Accident Hotspots and Providing a Model for Evaluating the Number and Severity of Accidents on Roadways

Gholamali Shafabakhsh[1,*], Yousef Sajed[2]

Received: 2019.02.13 *Accepted: 2022.06.19*

Abstract

Whenever an accident index exceeds a certain limit, then the critical conditions is created for a spot or section. Accordingly, that spot and section are identified as a hotspot or black spot. Therefore, determining the criterion for critical limits is always one of the essential challenges for traffic safety authorities. The purpose of identifying accident hotspots is to achieve high-priority locations in order to optimally and effectively allocate the safety budgets as well as to promote more efficient and faster safety at the road network level. Obviously, a suitable criterion for communities depends on different factors and parameters such as annual safety budgets, technology level, the amount of trained personnel, community operating strengths, and safety strategic plans and projects. Thus, it is not possible to prescribe a definite and stable criterion for different communities. In recent years, human, vehicle, road and environment have been recognized as the three main effective elements of the road transportation in the occurrence of accidents. In the present study, with combining the parameters related to accidents (including accident time, accident cause and accident severity), geometric parameters of the accident location (including: road width, shoulder width and radius of horizontal and vertical curves, road surface conditions, vertical slopes), and traffic parameters (including: average daily and hourly traffic volume, heavy traffic percentage and average speed), hotspots were identified by using the superior methods of Poisson regression and negative binomial distribution and based on the combined criteria of number and severity of accidents and equivalent damage factors.

Keywords: hotspots identification; regression models; number and severity of accidents

[*] Corresponding author. E-mail: ghshafabakhsh@semnan.ac.ir

[1] Professor, Faculty of Civil Engineering, Semnan University, Semnan, Iran

[2] Assistant Professor, Department of Civil Engineering, Faculty of Technology Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran

1. Introduction

Correct identification of accident prone areas has a significant effect on the reduction of road accidents and damages caused by it. Due to the lack of domestic studies and researches on the identification methods of accident hotspots, the introduction of a comprehensive and localized method for identifying hotspots is required more than before. It is obvious that paying more attention to the topic of the accident hotspots as the first and most important step in all road safety projects and localizing the identification methods for hotspots can reduce the growing problem of road accidents [Kazemi et al., 2012]. Suburban accidents constitute a major part of accidents. The statistics show that death in suburban roads accounts for more than 69 percent of the total deaths caused by accidents in the country. The targeted and systematic reduction of accidents requires a comprehensive road safety management.

Introducing accident hotspots is the first step in the road safety management process. Accident hotspots are sometimes recognized by definitions such as: hazardous road locations, high-risk locations, accident-prone situations, places requiring improvement and etc. [Montella, 2010]. With the development and implementation of road safety improvements, two major objectives are followed: the identification of accident hotspots and the assessment of areas with the highest potential for reducing accidents [Astaraki et al., 2013]. Investigating and studying the accident hotspots in Iran are in low and inadequate level due to the lack of a codified plan to identify and prioritize these spots and the appropriate database in which the identification of country hotspots can be registered and updated after supplying the validity and implementation of the corrective measures of its data. While neither are valid scientific methods used to identify and prioritize them, nor are the effectiveness and reduction of accidents in these spots evaluated after spending cost and securing them [Kazemi et al., 2012].

2. Foundations and Concepts

Accident Hotspots: There are many definitions for accident hotspots. However, conducted researches has emphasized that there is no comprehensive accepted definition of what is termed "dangerous". Elvik (2007) defined the hotspot as "every spot that has a higher number of accidents than other similar spots due to local risk factors". This definition refers to this concept that hotspots are the spots where the risk factors of the geometric and traffic design have a lot contribution in accidents and are reduced by the accident engineering strategies [Sadeghi et al., 2012]. An accident hotspot is a spot in which at least 10 accidents occurred during a three-year period, or at least four accidents occurred during one year [Rahimov and Haj Ali, 2011]. The definition of hotspot in different countries is presented in Table 1.

In general, there is no acceptable and definite definition for accident hotspots. Usually, accident hotspots are places in which there is a probability of high risk or accident occurrence. These spots are locations in which the potential for accidents is unacceptably high. The risk of accident occurrence is not the same throughout a road network. In certain situations, the level of risk is higher than the overall levels of risk in adjacent areas that more accidents occur in these situations. Although the term "hotspot" refers to a certain position, it is often used for sections of the road. These spots are usually found in certain areas of the road, such as crowded intersections and sharp curves. According to the Australian Department of Transportation and Economy, the locations are classified as hotspots or black spots after identifying the risk level and the probability of an accident occurrence in each location. As mentioned above, in certain locations, the level of risk is greater than the overall level of danger in the surrounding areas, and the accidents will occur more in these places with a high relative risk [Astaraki et al., 2013].

3. Methods for Identification of Accident Hotspots

In general, methods of identification and prioritization can be divided into two groups:

Reaction or accident-based method: that relies on statistical analysis of accident-based information to determine road safety problems.

Table 1. Definition of accident hotspot in different countries

Country	Accident Hotspot Definition
Germany	Road sections with the length of 300 m, occurrence of more than 3 similar accidents during one year, occurrence of more than 5 accidents during three years
England	Road sections with the length of 300 m, spot in which the total number of road accidents is more than 12 accidents over three years.
Spain	Road sections with the length of 1km, occurrence of more than 5 injury accidents or 2 fatal accidents during one year, occurrence of more than 10 injury accident or 5 fatal accident during 3 years
Czech	Road sections with the length of 250m, occurrence of at least 3 injury accidents during 1 year, occurrence of at least 3 similar injury accidents during 3 year, occurrence of at least 5 similar accidents during 1 year
Netherlands	Occurrence of at least 10 accidents, totally occurrence of at least 5 accidents with similar properties of analysis period is 3 to 5 year.

Source: Rahimov and Haj Ali (2011)

Table 2. Comparison of Criteria for hotspots in some countries (Source, Astaraki)

Country	Section's length	Frequency
Australia	A short section	During 5 years at least 3 accidents
England	300 meter	During 3 years 12 accidents
Germany	300 meter	During 3 years 8 accidents
Norway	100 meter	During 3 years 4 accidents
Portugal	200 meter	During 3 years 5 accidents
Thailand	variable	During one year at least 3 accidents

Preventive or observation-based method: that emphasizes on analyzing the physical and functional characteristics of the road for identifying existing road safety problems or road construction projects. This method is called Road Safety Inspection [Kazemi et al., 2012].

In identifying accident hotspots, the first method has been emphasized by more researchers, and its ability for identification of correct spots is more. But the first method requires accident information. Unfortunately, in many less developed countries, the importance of accurate recording of accidents for future uses is not explained and their accident database has many shortcomings. In our country, due to the long length of roads and the fewer police presence in roads with the lower importance grade, and most importantly, the failure to record many accidents that do not have plaintiff (generally single-vehicle or damage accidents), as well as the lack of recording geographic coordinates, there is no proper information for identifying accident hotspots with the first method. These issues highlighted the importance of using safety inspections.

In this research, the geometric and traffic characteristics of the study route are extracted based on field surveys and inspections. The recorded spots are reviewed and examined closely as accidents in COM forms of police 114 (Computerized forms of accident registration) in road, and the accurate geographical coordinates are recorded for them to have the ability to exact analysis and transfer to the route aerial map as well as GIS.

In general, nine methods for identifying hotspots are presented in various and valid sources. Each of them is briefly mentioned: Accident Frequency Method, Accident Rate Method, Accident Critical Rate method (Qualitative Control), Equivalent Property Damage Only Index (3 EPDO Index), Accident severity Method, Developed Accident Severity Method, Accident Number-Severity Method (Used in Organization of Road and Road Transport), Lost Cost Method (cost of losses + cost of heavy injuries + cost of light and possible injuries + cost of financial damage = lost value), Accident Density Method.

Road Safety Inspection: The principles of this method are based on existing inspections and identifying the weaknesses and shortcomings of the route. Normally, inspection costs will account for less than 0.5% of the total costs of the road construction project, but will result in significant investment return.

The risk is the probability of an accident occurrence, which can be expressed as a rate with a number of measurement values including time, traffic flow, road length, or road user interaction.

In a research by Haghighi, seven commonly applied HSID methods (accident frequency (AF), PIARC coefficient based equivalent property damage only (EPDO), P-value (Islamic Republic of Iran Ministry Roads and Urban development), accident rate (AR), combined criteria, empirical Bayes (EB), societal risk-based) were compared against six robust and informative quantitative evaluation criteria (site consistency test, method consistency test, total rank differences test, total score test, sensitivity test and specificity test). These tests evaluate each method performance in a variety of areas, such as efficiency in identifying sites that show consistently poor safety performance, reliability in identifying the same black spots in subsequent time periods .To evaluate the HSID methods, three years of crash data from the Kerman state were used. Analytical Hierarchy Process (AHP) method has been used for determination the importance coefficients of evaluation tests and as a result, showed that the total rank differences test is the most appropriate test. The quantitative evaluation tests showed that the EB method performs better than the other HSID method. Test results highlight that the EB method is the most consistent and reliable method for identifying priority investigation locations [Haghighi and Karimi, 2018].

4. Research Background

Studies conducted over the last few decades show that design elements influence the road safety. Design elements include cross-section features, horizontal path, vertical path, road shoulders, intersection design (level and non-level), lighting, accesses and how to control them, and pavement quality. In many conducted studies in this field and the proposed model, the fit analysis has been used to explore the relationship between accident rate and design elements.

Zaner Louis and Gupta evaluated the road hotspots using the Geographic Information System (GIS). They provided a map of the route features to accurately identify the location and characteristics of the hotspots, and placed them on the GIS software in the form of Time and Space Prioritization Layers by the weighting method [Zaner Louis and Gupta, 2003]. In the another study, three approaches to identification of hazardous road locations was compared: (1) Traditional reactive accident based approach, resulting in identification of accident black spots; (2) State-of-the-art empirical Bayes method using accident prediction model, which identifies critical locations, i.e. both real and potential black spots; (3) Proactive “preliminary” road safety inspection, identifying the risk factors, which may potentially increase accident occurrence and severity. Regional rural road network (approx. 1000 km) in South Moravia, Czech Republic was used. The methods were applied in identification and ranking of hazardous road locations in the studied network. It was found that black spot approach is not a suitable method, especially in low-volume road network with scattered accident occurrence. On the other hand risk index, based on road safety inspection, is a valid alternative, with ranking performance comparable to state-of-the-art empirical Bayes method [Ambros et al., 2016]. Another paper aims at presenting a novel approach, capable of identifying the location as well as the length of high crash road segments. It focuses on the location of accidents occurred along the road and their effective regions. In other words, due to applicability and budget limitations in improving safety of road segments, it is not possible to recognize all high crash road segments. Therefore, it is of utmost importance to identify high crash road segments and their real length to be able to prioritize the safety improvement in roads [Boroujerdian et al., 2014]. Saffarzadeh using statistics and information related to 580 km of the country's main roads, using a SPSS software, presented a mathematical model in which the effect of ADT on the risk index is significant [Saffarzadeh et al., 2006]. Safety visits is a method that was investigated in the study of Sajed and Azimi. In order to study the case, 14 tunnels of suburban roads of Ardabil province were selected and then important factors affecting the safety of tunnels, such as tunnel lighting and tunnel placement in archways were determined and Tunnel Safety Index (SI) were calculated for their safety assessment and compared with the accident statistics of tunnels. Finally, the Risk levels (RL) of the tunnels were proposed to prioritize the safety measures [Sajed et al., 2016]. The other study presents a methodology for ranking road safety hazardous locations using analytical hierarchy process (AHP). Road accident causes huge losses to the economy in terms of the cost incurred in hospitalization and treatment and damages to vehicles and property etc. There is an urgent need to reduce the number and severity of road accidents by implementing remedial measures at hazardous locations in the road network. Further, it is generally not possible to implement all remedial measures identified due to limited budget available for road safety improvement. The Safety Hazardous Index is developed using weight of safety factors and condition rating of safety factors. The Safety Hazardous Index is developed separately to evaluate safety at straight section, safety at curve section and safety at intersection. It is expected that this study will be useful in treating more hazardous locations depending on the available budget for road safety improvement [Agarwala1 et al., 2013]. A technical report develops, presents and tests a new international tool, the so-called Road Safety Development Index (RSDI), which indicates in a comprehensive and easy way the severity of the road safety situation in a specific country and/or in comparison with other countries. There are three pillars of outcomes involved in the framework of RSDI. One pillar is the People focus (road user behavior). The study suggests a master-list of performance indicators to be implemented for assessing road safety level in a country and for RSDI building. Based on the “master-list”, a short key list of performance indicators is chosen and classified into two primary categories that correspond to two groups of countries: LMCs “Less Motorized Countries” and HMCs “Highly Motorized Countries”. RSDI aggregates the key performance indicators into one single quantitative value (composite index) [Ghazwan Al-Haji, 2007].

A paper describes the application of Empirical Bayes (EB) approach for identifying and ranking hazardous junctions. Accident, traffic, and junction geometric/environment data from 203 four-legged and 186 three-legged signalized junctions across western part of Singapore were collected. Accident prediction models were developed and safety of the junctions was estimated. After that, hazardous junctions were identified using probability of selecting the worst site concept and then ranked using PSI (potential for safety improvement) and LH (level of hazard) criteria. A total of 38 junctions were found as hazardous. The result shows that the use of PSI criterion is more favorable than LH criterion as it is better able to detect the top hazardous junctions with the largest number of accidents in the study period [Kusumawati et al, 2010].

Regarding the proposed models, it can be assertively stated that the results of each model is reliable within the range of conditions in which the parameters of the model are taken into account. For example, weather conditions, driving behavior strongly influence the model results. Therefore, regardless of the changes in the factors involved, the direct use of a model and its results leads to the inconsistent results. For developing countries, the pattern of accidents is strongly influenced by human factors. What is important is the fact that the pattern of accidents in one section is influenced by the selected parameters and its nature is formed based on the spatial and temporal conditions of the selected variables. To this end, the process of accident model for Iran's roads has been reviewed and presented with the aim of identifying the parameters and factors involved in the rate of accidents and their relationship.

5. Theoretical Framework of Research

The accident prone location refers to the location in which the accident indicator exceeds a critical value (critical criterion). It should be noted that the location can be a spot or a road section of or a range. In this way, it is essential to know the types of indicators and related criteria for the identification of accident prone locations. In scientific sources, accident prone locations are often referred to as black spots, high accident areas or hotspots.

Whenever an accident index exceeds a certain limit, then the critical condition for a spot or section is created. Accordingly, that spot and section are identified as an accident prone location or black spot. Therefore, determining the criterion for critical limits is always one of the essential challenges to traffic safety authorities. The purpose of identifying high-accident locations is to reach priority locations in order to allocate optimally and effectively the safety budgets as well as to promote more efficient and faster safety at the level of the road network. Obviously, a suitable criterion for communities depends on factors and parameters such as annual safety budgets, technology levels, the amount of trained personnel, community operating strengths, and safety strategic plans and projects. Therefore, it is not possible to prescribe a definite and stable criterion for different communities. In recent years, human, vehicle, road and environment have been recognized as the three main and effective elements of road transportation in the occurrence of accidents.

In the present study, with combining the parameters related to accidents (including accident time, accident cause and accident severity), geometric parameters of the accident location (including: road width, shoulder width and radius of t horizontal and vertical curves, road surface conditions), and traffic parameters (including: average daily traffic volume, heavy traffic percentage and average speed of route in accident day), as well as the use of three-year statistics and information (2015-2017), which have taken place over 130 km from the main two-lane Ardebil-Sarcham suburban road and inserted in the police accident registration forms and all the information along with the geographical coordinates of the spots on the route has been reviewed, the route accidents in different sections have been modeled and evaluated using Poisson regression models and negative binomial distribution of the number and severity of accidents in the STATA software.

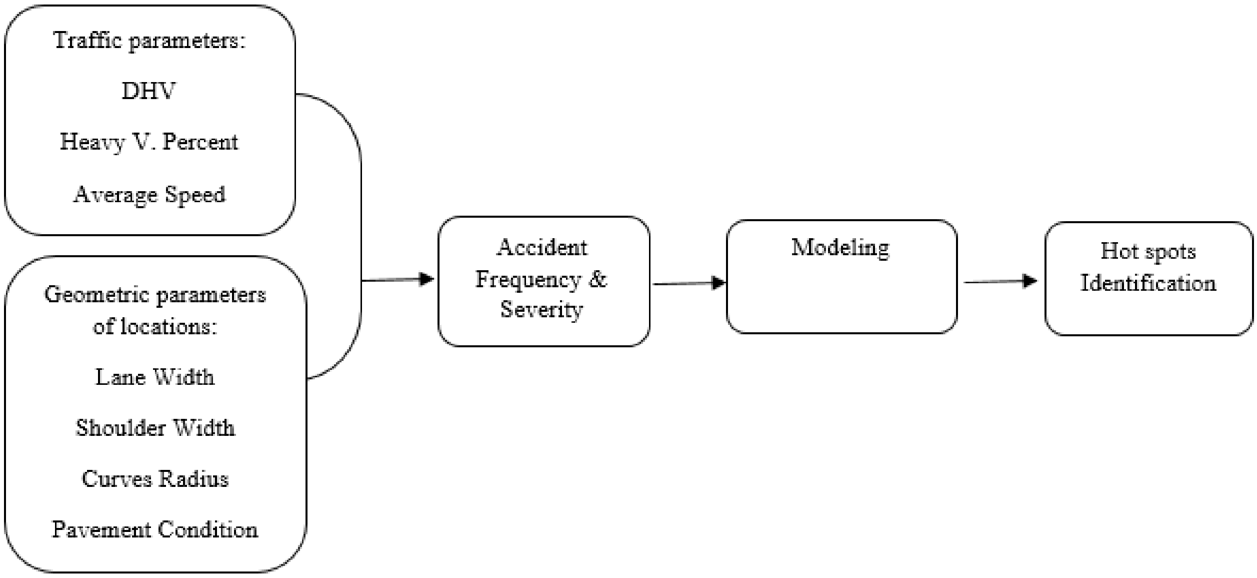


Figure 1. Conceptual model of research

5.1. Regression Models

The most common statistical models in the discussion of road safety are the Poisson regression model and negative binomial distribution. These methods are used to model discrete, independent and positive events. These models are employed to select variables and also for modeling accidents [Lord et al., 2008]. Due to the fact that the accident data has an over dispersion (in the sense that the data variance is greater than the mean), a negative binomial model is used to overcome this problem. For such data, the Poisson method should not be used. For example, if the Poisson model is used to estimate the number of expected accidents, a great difference is created between occurred and estimated accidents [Hauer, 2001]. A negative binomial model is the modified Poisson model for solving problems of data with over dispersion. This model is based on the assumption that the Poisson parameter has a gamma distribution. The model is derived from a closed equation and the mathematical rules for solving the relationship between the mean and variance are almost straightforward. The negative binomial model is obtained by rewriting the Poisson parameter for each observation i as follows:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \quad (1)$$

Where: EXP) ε_i (is the gamma distribution error with the mean 1 and the variance α. Adding this equation allows the variance to differ from the mean as follows:

$$VAR[y_i] = E[y_i][1 + \alpha E[y_i]] = E[y_i] + \alpha E[y_i]^2 \quad (2)$$

Poisson's regression model is a mode of a negative binomial model in which α reaches zero. It means that the choice of one of these two models depends on α. α is usually called the over dispersion parameter. The Poisson Gamma model is the most commonly used model for estimating the frequency of accidents.

5.2. Data and Modeling

Data from three years of Ardabil-Sarcham suburban road accidents were processed in EXCEL environment and entered into the software environment of STATA for regression modeling. The output of the model and the definition of the parameters are given in Tables 3 and 4. Figure 2 indicates that model validation by indicating Model estimation vs. Observation. Table 5 shows Accident indexes on Ardebil-Sarcham roadway for EB and HPG models and “P” and EPDO indexes.

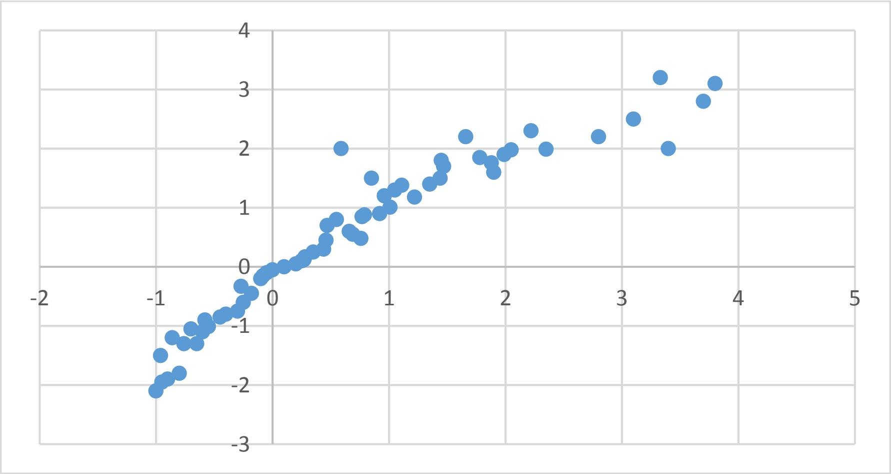
Table 3. Input variables to the model

Variable name	Specifications
volume	Traffic volume
P	Traffic volume of private cars
NP	Traffic volume of non-private cars
AvSpeed	average speed
DV	Dependent variable (with coefficients)
D	Death number
J	Injury number
Lic	Is the culprit vehicle non-native (1 for yes and 0 for no.)

Table 4. The output of the Poisson model at the final stage (4)

DV	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
Weekend	.3464802	.0646013	5.36	0.000	.2198641	.4730964
P	.0021118	.0004542	4.65	0.000	.0012215	.0030021
Faslp	-.3579852	.0873164	-4.10	0.000	-.5291222	-.1868482
lic	.2887291	.0666041	4.34	0.000	.1581875	.4192707
bayaekyach~h	.1778359	.0635939	2.80	0.005	.0531941	.3024777
Pghosofoghi	.6667388	.0764326	8.72	0.000	.5169336	.816544
Pshib	-.3591373	.0937279	-3.83	0.000	-.5428405	-.1754341
PTaghato	.2278146	.0796781	2.86	0.004	.0716485	.3839807
PMaskooni	.7861588	.1287586	6.11	0.000	.5337966	1.038521
Faslz	-.1984738	.0896359	-2.21	0.027	-.3741569	-.0227907
_cons	1.435312	.1230199	11.67	0.000	1.194198	1.676427

Poisson regression
Number of obs = 330
LR chi2 (10) = 256.88
Prob > chi2 = 0.0000
Log likelihood = -729.41033 Pseudo R2 = 0.1497



Model estimation VS Observation

Figure 2. Model validation-without errors estimation

Table 5. Accident indexes on Ardebil-Sarcham roadway

Kilometer	Location	Geometric characteristics	Frequency index	EPDO	EPDO index	EB model estimation	Potential for improvement of EB	P index	HPG model estimation
30-31	Hefz abad	Intersection-horizontal	16.8	81	-1.56	81.6	45.2	12.31	2.45

		curve with vertical slopes							
2-3	Exit of Ardebil	Intersection-straight segment	15.8	39	-4.3	40.1	35.1	5.93	1.95
20-21	Hir	Intersection-uphill slope	15.8	80	-1.3	80.8	57.1	12.16	2.76
44-45	Khalafloo	Steep slope	13.8	44	-3.2	45.2	39.1	6.69	2.13
17-18	Kargan	Residential area-horizontal curve	10.8	45	-2.25	45.7	43.2	6.84	2.33
27-28	Bodalaloo	Residential area- Steep slope	10.8	38	-2.8	39.1	40.1	5.78	2.19
11-12	Arallo	Residential area	9.8	30	-3.3	31.2	38.7	4.56	1.85
67-68	Gare geshlag	Intersection-Insufficient vision	8.8	63	+0.3	64.1	55.2	9.58	2.66
111-112	Between of Tunel 11&12	Longitudinal Slope-Bridge	4.8	85	+8.2	86.3	48.1	12.92	2.38

6. Discussion and Conclusion

The purpose of identifying accident hotspots is to achieve high-priority locations in order to optimally and effectively allocate the safety budgets as well as to promote more efficient and faster safety at the road network level. In the present study, with combining the parameters related to accidents (including accident time, accident cause and accident frequency & severity), geometric parameters of the accident location (including: horizontal and vertical curves, curvature, vertical slopes and curvature*slope parameter), and traffic parameters (including: average daily and hourly traffic volume, heavy traffic percentage and average speed), hotspots were identified by using the superior methods of Poisson regression and negative binomial distribution and based on the combined criteria of frequency and severity of accidents and equivalent damage factors (HPG model). MATLAB-2015a and STATA software were used. Non-native plumbing (lic), curvature, slope, section length and residential area had more significance, and their coefficients indicated the significant effect of these parameters on the occurrence of the frequency and severity of accidents in hotspot locations. Results that show "HPG" and "EB" models have the same and exact outputs for identification and prioritize of hotspots approximately, rather than "P" and "accident frequency" indexes. On the other hands, the "P" index has better results in comparison with "accident frequency" index. In oral, "HPG" model can identify and prioritize hot spots better than other indexes. Table 6 shows prioritize of hotspots for 9 locations based on results of Table 5.

Table 6. Prioritize of hotspot locations on Ardebil-Sarcham roadway based on HPG estimation and other indexes

	Location	Frequency index	EPDO index	EB index	P index	HPG estimation
1	Hefz abad	1	7	4	2	3
2	Exit of Ardebil	2	2	9	7	8
3	Hir	3	8	1	3	1
4	Khalafloo	4	4	7	6	7

	Location	Frequency index	EPDO index	EB index	P index	HPG estimation
5	Kargan	5	6	5	5	5
6	Bodalaloo	6	5	6	8	6
7	Arallo	7	3	8	9	9
8	Gare geshlag	8	9	2	4	2
9	Between of Tunels 11&12	9	1	3	1	4

7. References

- Agarwala, K. Kumar Patil, P. Mehar, R. (2013) “A Methodology for Ranking Road Safety Hazardous Locations Using Analytical Hierarchy Process Pradeep”. 2nd Conference of Transportation Research Group of India (2nd CTRG), Procedia - Social and Behavioral Sciences 104, pp. 1030 – 1037.

- Al-Haji, Gh. (2007) “Road Safety Development Index (RSDI)”, Technical Report, Department of Science and Technology Linköping University, SE-601 74, Norrköping, Sweden.

- Ambros, J., Havranek P., Valentova, V., Krivankova, Z. and Striegler, R. (2016), “Identification of hazardous locations in regional road network –comparison of reactive and proactive approaches”. Transportation Research Procedia, Vol. 14, pp. 4209 – 4217.

- Astaraki, G., Rassafi, A., Momeni, F., And Amini, B. “in Persian” (2013) “Application of multi-criteria decision in identified hotspots: Using data envelopment analysis and analysis of the Summit”. Transportation engineering Journal.

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

- Elvik, R. (2007) “State-of-the-art approaches to road accident black spot management and safety analysis of road networks”. Report 883, Institute of Transport Economics, Norvegian Centre for Transport Research.

- Haghighi, F. and Karimi Maskooni, E. “in Persian” (2018) “Evaluation and Statistical Validation of Black-Spots Identification Methods”. International Journal of Transportation Engineering (IJTE), Vol. 6, No. 1, pp. 1-15.

- Hauer, E. (2001) “Overdispersion in Modelling Accidents on Road Sections and in Empirical Bayes Estimation”. Journal of Accident Analysis & Prevention, Vol. 33, No. 6, pp. 799-808.

- Kazemi, A., Zoghi, H. “in Persian” (2011) “Identify and prioritize black spots on suburban roads and software”. Eleventh Conference of transportation engineering and traffic Iran, Transportation and Traffic Organization of Tehran, Deputy Transport and traffic of Tehran Municipality, Iran.

- Kusumawati, A. Ganesa, B. J. Diew, W. Y. (2010) “The Application of Empirical Bayes Approach for Identifying and Ranking Hazardous Junctions Case Study: Singapore Signalized Junctions”, Journal of the Eastern Asia Society for Transportation Studies, Vol.8.

- Montella, A. (2010) “A comparative analysis of hotspot identification methods”. Journal of Accident Analysis and Prevention, Vol. 42, pp. 571–581.

- Rahimov, K. and Haj Ali, D. “in Persian” (2011) “Providing a model for identifying hotspots on the rural roads using multi-criteria decision-making”. 6’Th National Congress of Civil Engineering, 6 and 7 May, Semnan University, Semnan, Iran.

- Sadeghi, A. And Ayati, I. “in Persian” (2012) “Identification and prioritization of accident-prone parts of the segmented approach path and data envelopment analysis”. Transportation engineering.

- Saffarzadeh, M., and Fakhro, A. “in Persian” (2006) “Assessment of techno-economic model for the construction and operation of freeways and expressways”. Journal of Transportation, Sppring, No 1.

- Sajed, Y. and Azimi, J. “in Persian” (2016) “Evaluation of tunnel safety of rural roads by AHP method (case study: tunnels of Ardabil province roads). M.Sc. Thesis, Islamic Azad university of Ahar branch.