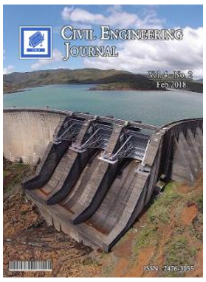
Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 2, February, 2018



Optimization of the Allowable Speed on Iran's Freeways to Reduce Violations and Accidents, Using Zero-Truncated Poisson Regression Model

Mansour Hadji Hosseinlou [a], Alireza Mahdavi [b*], Mojtaba Alinezhad [c]

[a] *Associate Professor, Department of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran.*

[b] *Ph.D. Student, Department of Civil Engineering, K. N. Toosi University of Technology, Tehran, Iran.*

[c] *M.Sc. Student, Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.*

Received 20 August 2017; Accepted 02 February 2018

Abstract

Countries from all over the world including Iran, consider different maximum allowable speeds to control and maintain traffic safety on their freeways, but these actions have not been successful even with the police surveillance. Even though speeding is not the only cause of accidents, past studies indicate that speed plays a vital role in such events. Since respecting the speed limits have not prevented driving violations and traffic accidents, there's doubt among decision-makers, about the applicability and safety of these legal speed limits in different weather and traffic conditions. They think perhaps there is a need for an optimized and safe speed after doing required studies. Even in the police instructions and notifications in unfavorable weather conditions, the word "safe speed" is used more than the "legal speed" and its limit is not mentioned and its determination is assigned to drivers according to their mental and physical conditions, type of vehicle, and the weather condition. This matter leads to uncertainty for drivers in selecting the right speed.This research is intended to achieve a safe and optimized speed for freeways in Iran, by considering a reasonable adjustment which is acceptable by the drivers so that a substantial decrease in driving violations and accidents could be observed. This work is done by using models developed for predicting violations and accidents on Iran's freeways. The results indicate that by reducing the allowable speed of freeways from 125km/h to 105 km/h, a 48% and 23% reduction of violations and traffic accidents could be achieved.

Keywords: Freeways; Safe and Optimized Speed; Zero-truncated Poisson; Maximum Allowable Speed; Driving Violations; Traffic Accidents.

1. Introduction

Because of the relative advantages of freeways in comparison to other types of rural roads, construction of them is increasing. They are welcomed by private sectors and banks, due to the produced revenues. According to the last statistical yearbook of "Iran Road Maintenance and Transportation Organization" until 2015, 2401 kilometers of freeways, which connect several principal cities of the country, have been built. Freeways are constructed for many purposes, most important of which are speed and safety. Thus adequate knowledge about the influencing environmental factors is of particular importance and must be studied and scrutinized continuously. On the one hand, providing both high speed and traffic safety at the same time is not easy, because these two factors are not acting in the same direction, and on the other hand, to improve one of them, the other one cannot be overlooked. As a result, one must seek to optimize both factors by considering all the conditions and determine an optimized speed which is

* Corresponding author: mahdavi@mail.kntu.ac.ir

http://dx.doi.org/10.28991/cej-0309104

acceptable to the drivers and provides maximum safety. This approach is the only way that doesn't impact the philosophy of constructing freeways (transferring rapidly from one place to another one) and maintain their attractiveness for road users. The primary purpose of this study is to find and introduce an optimized speed namely "safe speed," by reducing the allowable speed* of freeways reasonably, to provide maximum traffic safety. A speed which can provide an appropriate and acceptable balance between safety and quick access on freeways, because the enforcement of current allowable speeds has not controlled and reduced the increasing number of accidents on freeways in Iran. The number of accidents occurred in allowable speed and even speeds less than that, is another reason for justifying the importance of doing this research. Figure 1 shows the variation of annual accidents on freeways in Iran, from 2013 to 2015.

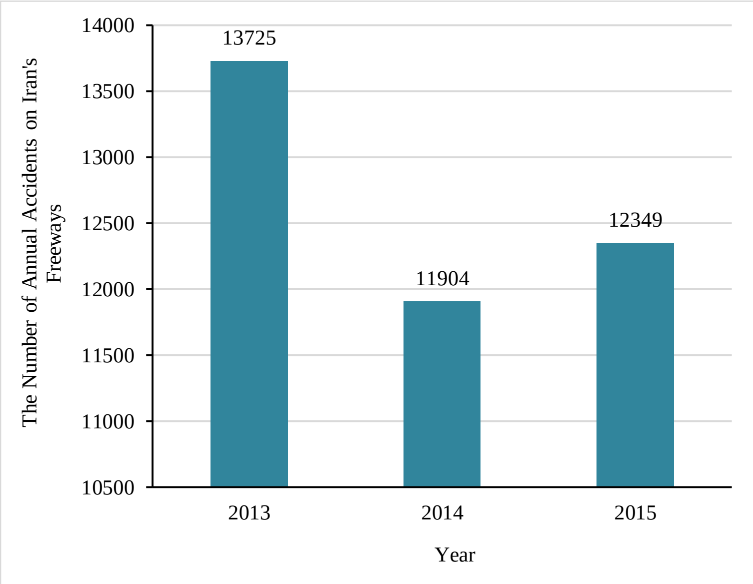


Figure 1. The variation of annual accidents on Iran's freeways from 2013 to 2015

Furthermore, the numbers written in Table 1 indicate that within the years 2013 to 2015, 44%, 47%, and 46% of accidents have occurred in speeds less than 125 km/h (Legal allowable speed on Iran's freeways). We can also add a percentage of accidents with undefined speeds to these numbers.

Table 1. The number and percentage of accidents and their corresponding speeds during the past 3 years (2013:2015)

Year	Total accidents	The percentage of accidents corresponding to speeds Less than 70km/h	The percentage of accidents corresponding to speeds between 70 and 125 km/h	The percentage of accidents corresponding to Undefined Speeds
2013	13725	3.76	40.68	**55.56**
2014	11904	3.89	43.32	**52.79**
2015	12349	3.90	42.47	**53.63**

Although the term "Safe Speed†" is widely used by the police in the driving culture of the country, it has not been determined in the road's safety regulations and only has been merely defined qualitatively. The police advise the drivers to drive with safe speed in critical weather and traffic conditions, while the drivers are confused about choosing the right speed to drive safely through these circumstances. Although selecting safe speed can be subjected to different factors such as traffic and weather conditions, driver's physical and mental condition, and vehicle type, conferring this task to drivers has not been a useful solution and has caused some juridical controversy which will complicate the judgment about the blameworthy person in the accidents. Thus it is crucial to introduce logical and practical limits for this speed, based on some critical and determinant factors. Other countries also have experienced reduction and limitation of speed to increase safety. In 1861 for the first time in the history, USA determined 16.1 km/h as a speed limit. At another time, they reduced the speed limit on their freeways to 95 km/h to save fuel. In 2005 in France, again to save fuel and reduce number of the accidents, the speed limit decreased to 115km/h. Again they succeeded to reduce accidents up to 50% by reducing the speed limit. In England from 1930 to 1965 most of the

* The allowable speed for each road is the maximum speed that drivers are allowed to select, according to the regulations of their countries. (Article 126 of Driving Violations' Law of Iran).

† "Safe Speed" is a speed with which a driver can stop the vehicle before collision with any obstacle, provided that the negative acceleration applied to the driver and the passengers is less than the allowable limit.

freeways had no speed limit, hence number of the accidents increased, especially in foggy conditions. Thus a speed limit of 112 km/h was determined, and later in 1967, it was reduced to 100 km/h. For the moment Austria and United Arab Emirates with a 160 km/h speed limit, have the highest legal allowable speed on their freeways, though 57% of freeways in Germany have no speed limit. The average of allowable speed for existing freeways in Iran has been determined from 70 km/h to 120km/h. The amount of this speed for other countries is as follows: USA (105 to 129 km/h), Canada (90 to 110 km/h), Norway (100 km/h), France (110 to 130 km/h) and Denmark (130 km/h). Nepal has an average speed of 40 to 50 km/h in its roads. This country is famous as the country without speed limit, and approximately 30% and 10% of its roads have speed limits and surveillance systems respectively. Allowable speeds are often written as a number on freeway signs and are installed on intersections, entrances and road shoulders to inform drivers. In Europe speed limits on freeways are shown at the entrance of each region and are repeated every 200 to 500 meters. Sometimes the reason for speed reduction is environmental, given that reducing speed can reduce air pollution and pollutants' emission. Minimum speed on freeways is also determined in some countries because low speed could be also hazardous and cause disorder in traffic flow. The number of violations and accidents and the average speed of vehicles for freeways in Iran in such incidents are listed in table 2 for the years 2013 to 2015. Allowable speed for most of the roads is studied and will be automatically changed for different weather and traffic conditions. It is usually determined according to the design speed, geometric design, safety and other factors such as available facilities on the road, accidents' reports and even political issues.

Table 2. The number of violations and accidents on Iran's freeways and their corresponding average speed

Year	Number of Violations	Number of Accidents	Average Speed
2013	11308	12134	91.47
2014	11064	11560	89.27
2015	11196	12160	91.82

As it is evident in Table 2, all of the average speeds are smaller than the maximum allowable speed on freeways, indicating that the total violations and accidents have occurred in a speed less than the maximum allowable speed and this matter is another reason for doing this study. This research is based on the past literature, and its objective is to complete those studies at first and then make their results more practical. It should be noted that up to the present time studies done about the freeways' safety have not been adequate. Mahdavi [1] presented two models for predicting the number of violations and accidents on Iran's freeways. In these models, the speed was modeled alongside other influencing factors such as traffic volume, peripheral landscapes, the number of interchanges and passing lanes,etc. to predict violations and accidents using Zero-truncated Poisson regression models. Using these pridictive models, one can modify the speed and achieve an optimized or safe speed. Though the speed has been considered as one of the leading causes of the accidents, the result of different studies is inconsistent. Imprialou et al. [2] modeled a set of data using a multivariable lognormal Poisson regression to indicate part of these inconsistencies. The speed management is an essential strategy for improving the safety on freeways, due to the sharp relationship between speed and accident occurrence and its intensity. The main idea which comes to one's mind about controlling speed operatively is to apply speed limit, but these limits must be safe and credible to receive the agreement of drivers. This work means that the road users must obey the allowable speed limits as long as they are logical under the given circumstances, thus if the speed limits fit the picture of the freeways which drivers have in their minds, then they will be acceptable to them [3]. Wilmots et al. [4] studied the impact of using or not using limiting warning signs on the road shoulders and used a general linear regression model of analyses, to control the outputs. The results showed a remarkable reduction in speed, at the time of using these facilities in the test section. Extending these results, the speed control with advanced warning signs is more efficient than merely controlling it. A driver assistant system can be used to maintain the safe speed and longitudinal distance. Its positive effects include facing less hazardous situations, reducing dangerous longitudinal distances, shorter reaction times, and better interaction with vulnerable road users on intersections [5]. In the field of Intelligent Transportation Systems (ITS), using Intelligent Speed Adaptation (ISA) is considered as a valid action for reducing the number of traffic accidents [6]. However, it should be noted that many people are still in doubt about its effects on the traffic safety. The significant role of ISA could be understood using outputs of driving simulator combined with participant's awareness, especially in situations in which sounds can be used to identify the state of consciousness of drivers who are aggressive. Using this method leads to the reduction in driving speed and improvement in traffic safety. Batrakova and Gredasova [7] considered the effect of road condition on traffic safety, based on the interaction of driver and traffic environment. They obtained an optimized speed for various road conditions. The criterion for this optimization was the reliability of driver's performance. Hadji Hosseinlou et al. [8] in a case study about the Shiraz-Marvdasht motorway located in south of Iran, used experimental and field data along with data from simulations to determine how speed limit is related to emissions of pollutants and to calculate the societal cost of traval. They concluded that from a societal perspective, the optimal speed would be 73 km/h and from a road user perspective, it would be 82 km/h. It should be noted that the reason for enforcing speed limit is not always the safety purposes. The traffic chaos can also be resolved by implementing different speed limits [9].

2. Materials and Methods

2.1. Research Method

As it was mentioned above, the Zero-truncated Poisson regression models which had been developed for predicting the number of violations and accidents on freeways in Iran, were used for doing this research [1]. The most common regression model used for the count data is the Normal Poisson distribution. When considered data are count and non-zero, the zero-truncated Poisson distribution could be an appropriate one for modelling these kinds of data. In this study hourly violations and weekly accidents were modelled, using zero-truncated Poisson regression model. The Multi-variable models were also employed to validate the effect of each variable in these models. All the stages related to the estimation of regression coefficients and evaluating the significance of independent variables were done using R software. These models have been developed using the latest data available in the police database and "Ministry of Roads and Urban Development" of Iran from 2013 to 2015 to predict the number of possible violations and accidents on freeways. The authors extracted data corresponding to 18 freeway sections in both directions for the period 2013-2015 from this internet database [10]. These road sections consist of 1797 kilometres of freeways which is equivalent to 75 percent of the total length of existing freeways in Iran. The independent variables used in this study include traffic volume, average speed, number of interchanges and passing lanes, peripheral landscapes, and paying the toll. The authors employed aerial and satellite photos along with on-site inspections, to determine the number of passing lanes and interchanges, and also to assess the percentage of peripheral landscapes. They divided the length of each section on both directions in aerial and satellite photos into sub-sections with a specific scale, to determine the percentage of peripheral landscapes (natural and artificial views) for them. Then they calculated the average of these rates and considered it as the percentage of the peripheral landscapes on that section. At the time of doing this research, only two freeways of Tehran-Karaj and Tehran-North were toll-free, and others required paying the toll; thus a coding system was considered for this variable in the models. The authors introduced the fee by two codes, the number 1 representing freeways which require toll paying and 0 representing toll-free ones. The weekly accidents and hourly violations (the sum of three common violations of illegal speed, tailgating, and illegal overtaking from the right side), have been considered as dependent variables to develop these models.

2.2. The Model Used for Prediction of Violations

The Equation 1 is used for the prediction of hourly violations:

$$TH=Q\times \exp(-3.027881+0.033318\times SA+0.003536\times L-0.017330\times LS+0.036877\times NI-1.011636\times NL+1.11020\times TP) \quad (1)$$

The Variables used in this equation are defined as:

TH: The number of hourly violations (per 100 passing vehicles)

SA: The average speed of passing vehicles (km/h)

Q: The number of passing vehicles (by thousand vehicles)

L: Road length (km)

NL: The number of passing lanes for each direction

NI: The number of intersections

LS: The percentage of peripheral landscapes in the freeway's length

TP: Toll-paying (0 for toll-free freeways and 1 for non-free ones)

2.3. The Model Used for Prediction of Accidents

The Equation 2 predicts the number of weekly accidents:

$$NACC=\exp(1.4772868+0.001433Q+0.0133686SA+0.022377L-0.0156181LS+0.0279483NI-0.4457642NL) \quad (2)$$

The Variables used in this equation are defined as:

NACC: The number of weekly accidents

SA: The average speed of passing vehicles (km/h)

Q: The number of passing vehicles (by thousand vehicles)

L: Road length (km)

NL: The number of passing lanes for each direction

NI: The number of intersections

LS: The percentage of peripheral landscapes in the freeway's length

2.4. The Processing of Models

Each of the models mentioned above was processed to achieve a safe speed and come to a conclusion. All of the independent variables were assumed to be constant, and the models were tested using varying speeds. The range of selected speeds was from speeds less than allowable speed up to the ones more than that, so that the average speed of passing vehicles in the past three years and also the legal allowable speed of the freeways lie in this range. The speed ranges assumed for testing models and also the predicted number of hourly violations and weekly accidents on freeways corresponding to these speeds, have been shown in Tables 3 and 4.

Table 3. The amount of violations predicted for different speeds, using the proposed model

SA	75	80	85	90	95	100	105	110	115	120	125	130	135	140
TH	124	147	173	204	242	285	337	398	470	556	656	775	916	1082

Table 4. The amount of accidents predicted for different speeds, using the proposed model

SA	75	80	85	90	95	100	105	110	115	120	125	130	135	140
NACC	519	555	593	634	678	724	775	828	885	947	1012	1082	1157	1237

The correlation between the Speed and the number of hourly violations and weekly accidents can be seen in Figure 2 and 3.

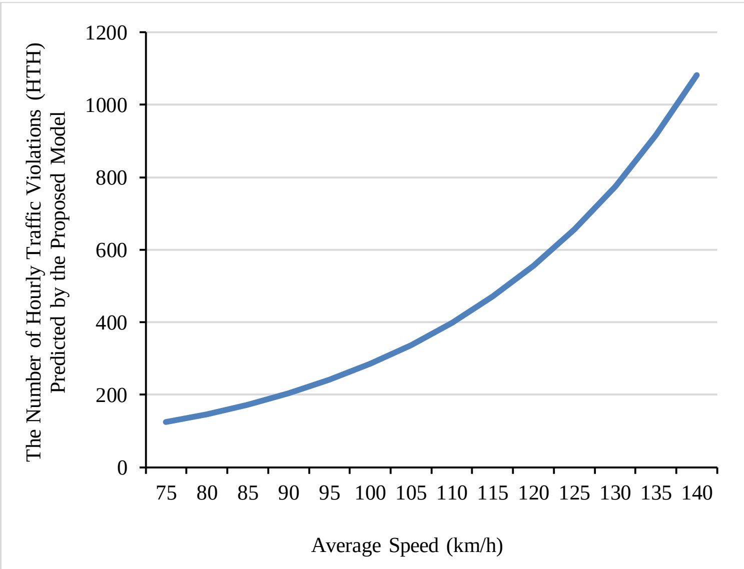


Figure 2. The number of hourly traffic violations predicted for different speeds, using the proposed model

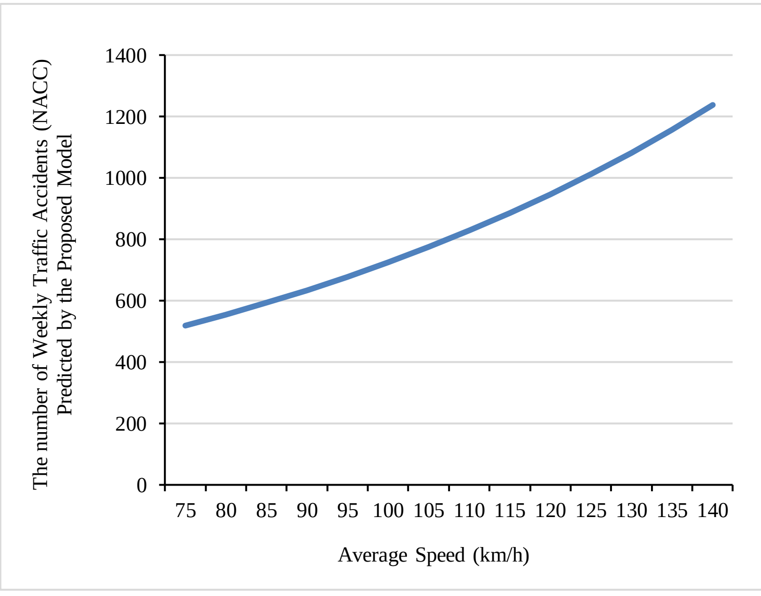


Figure 3. The number of weekly traffic accidents predicted for different speeds, using the proposed model

These curves (Figure 2 and 3) which were drawn using the numbers in Tables 3 and 4, give a better and simpler means for analyzing the calculated data. Slope variation of above curves for each pair of speed has been separately calculated and mentioned in Table 5.

Table 5. The slope of violations and accidents curves for each pair of speed

Average Speed (km/h)	75		80		85		90		95		100		105		110
Slope (Violations)		4.6		5.2		6.2		7.6		8.6		10.2		10.4	
Slope (Accidents)		7.2		7.8		8.2		8.8		9.2		9.8		10.2	

Average Speed (km/h)	110		115		120		125		130		135		140
Slope (Violations)		14.2		17.2		20		23.2		28.2		33.2	
Slope (Accidents)		11.4		12.4		13		14		15		16	

3. Results and Discussion

The results obtained from the analysis of violations and accidents models for the speed range between 70 and 140 km/h indicate that the speed of 105 km/h could be an acceptable choice as safe speed. We can conclude this by investigating the calculated slopes for each pair of speed in Figure 2 and 3, in which the slope of violations curve between 105 and 110 km/h is more than the intervals before that. In other words, the number of violations increases as the speed increases up to 105 km/h. This matter is repeated for the accidents curve in the same speed interval (between 105-110 km/h).The curves also have relatively high slopes in the speeds higher than 125 km/h (Maximum allowable speed in Iran). By processing the models using speeds mentioned in table 5, the number of predicted hourly violations and weekly accidents for the speeds higher than 125 km/h on freeways was 656 and 1012 respectively, which could decrease to 337 hourly violations (48% reduction) and 775 weekly accidents (23% reduction).

4. Conclusion

Collected statistics from the police reports within the years 2013 to 2015 indicate that the average number of accidents on freeways in Iran has been 12659, instances of which 3.87% was fatal, 20.41% was injury and 75.72% was property damage accident. According to these statistics and the results of this research, it can be concluded that the reduction of allowable speed to 105 km/h on freeways has the potential to prevent 490 fatalities, 2584 injuries and 9586 property damages from occurring. Also, the cost of urban and rural accidents in Iran is 7% of Gross National Product (GNP) annually, which can be reduced dramatically by doing this action and spent in other sectors in the country [11]. The average speed of passing vehicles on freeways has been 90.85 km/h in the past 3years (Table 2), thus selecting 105km/h as the optimum and safe speed would be acceptable by the drivers and does not have any contrast with the application of the freeways as expressways. On the other hand, a remarkable decrease in the number violations and accidents on freeways, can reduce mental and social consequences (such as the orphanage, disability, etc.) resulting from accidents and increase life expectancy in the community.

5. References

[1] Mahdavi, A., The Study of Traffic Infringements Engineering Effects, on Traffic Safety Promotion in Iran Freeways (Fourth Chapter), in Civil Engineering. 2016, K.N. Toosi University of Technology.

[2] M.Imprialou, M.-I., et al., Re-visiting crash–speed relationships: A new perspective in crash modelling. Accident Analysis & Prevention, January 2016. 86: p. 173-185. doi: 10.1016/j.aap.2015.10.001

[3] Augeri, M., P. Cozzo, and S. Greco, Dominance-based rough set approach: An application case study for setting speed limits for vehicles in speed controlled zones. Vol. 89. 2015.

[4] Wilmots, B., et al., Speed control with and without advanced warning sign on the field: An analysis of the effect on driving speed. Safety Science, 2016. 85: p. 23-32. doi: 10.1016/j.ssci.2015.12.014

[5] Adell, E., A. Várhelyi, and M.d. Fontana, The effects of a driver assistance system for safe speed and safe distance – A real-life field study. Transportation Research Part C: Emerging Technologies, 2011. 19(1): p. 145-155. doi: 10.1016/j.trc.2010.04.006.

[6] Ando, R. and Y. Mimura, An analysis on possibility of intelligent speed adaptation in terms of drivers' consciousness. Journal of Traffic and Transportation Engineering (English Edition), 2015. 2(3): p. 136-144. doi: 10.1016/j.jtte.2015.03.002

[7] Batrakova, A. and O. Gredasova, Influence of Road Conditions on Traffic Safety. Procedia Engineering, 2016. 134: p. 196-204. doi: 10.1016/j.proeng.2016.01.060

[8] Hadji Hosseinlou, M., S.A. Kheyrabadi, and A. Zolfaghari, Determining optimal speed limits in traffic networks. IATSS Research, 2015. 39(1): p. 36-41. doi: 10.1016/j.iatssr.2014.08.003.

[9] Cao, J., et al., Exploring the impact of a coordinated variable speed limit control on congestion distribution in freeway. Journal of Traffic and Transportation Engineering (English Edition), 2015. 2(3): p. 167-178. doi: 10.1016/j.jtte.2015.03.005.

[10] Organization, R.M.a.T. Iran Road Maintenance and Transportation Organization Website. Available from: www.rmto.ir.

[11] Ayati, E., The Cost of Accidents, Theory and Practise. 2009: Ministry of Road and Urban Development. 750.