A Model for Predicting Students' Accidents in the Vicinity of Rural Roads based on Geometric and Traffic Parameters

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Abstract:

Students are among the most vulnerable road users because of their age, physical characteristics and the scale of awareness they gain from their surroundings. Recent statistics indicate that about 40 percent of road accident fatalities are pedestrians, 30 percent of which are under 18 years old. Based on the fact that almost two million Iranian students study in the vicinity of rural roads, this paper aims to develop a model for predicting the risk of students' accidents near the aforementioned schools. Therefore, by gathering data from schools located in rural areas, schools are divided in three categories which are: no risk (no accidents/year), medium risk (one accident/year), and high risk (two or more accidents/year). A multinomial logit (MNL) model has been chosen and the utility function was considered as a combination of variables such as road width, functional speed, presence of school guardian, number of students and the ratio of average daily traffic to the distance of schools from roads. Results indicate that the proposed model can predict the risk of accident occurrence with the accuracy of more than 70 percent. Meanwhile, school guardian is known as an important variable in the prediction model. Also, results show the important role of the road width and proposed ADT/Dis variables.

Keywords: Students' accidents, schools in the vicinity of roads, accident prediction model, multinomial logit, school guardian.

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1. Introduction

In comparison to urban areas, pedestrians are much more vulnerable in rural areas where they might be struck by high speed or larger vehicles. The accident statistics in all around the world indicates that though pedestrians are involved in only a small percentage of accidents, a considerable percentage of accident fatalities are related to this group. For instance, only 2 percent of accidents in USA were related to pedestrians, while 12 percent of accident fatalities belonged to pedestrians [NHTSA, 2003]. In this respect, pedestrians confront even worse conditions in developing countries. These countries, due to problems such as lack of proper safety actions in road infrastructure, lack of attention to construction of land uses according to the hierarchy of roads and lack of specialized human forces in transport safety planning, suffer from more accidents compared with developed countries [WHO, 2003].

Despite the fact that children have less mobility in transportation networks than adults, they are considered as the main victims of traffic accidents. Because of the aforementioned reasons, this problem is more severe in developing countries. As indicated in the research implemented by the World Health Organization in 2002, 97 percent of the total 180500 children who were killed in traffic accidents around the world belonged to low to average income countries [WHO, 2003]. Furthermore, results in international scales show that accidents will mostly cause severe injuries or even death to children.

Children are usually more vulnerable to accidents, mostly because of their lack of knowledge to estimate the speed of moving vehicles and recognizing safe gaps in traffic stream and because of their small physical characteristics which makes them difficult to be observed by the drivers [Trimothy et al., 2009].

Children, particularly at the age of 5 to 15 years, which are categorized as students, are exposed to accidents due to their frequent mobility for going to school. Accidents are the second main reason for unintentional harms and injuries caused to death among children in this age group [Parisi Associates Transporting Consulting, 2003]. Children of middle and elementary school age represent the most vulnerable and difficult to protect pedestrian age-groups in the United States. Children at the age of 14 and less are involved in nearly 7 percent of pedestrian fatalities and 20 percent of pedestrian injuries in the United States [McDonald, 2008].

Determination of why pedestrian crashes occur so frequently for the 14 and under age group is a complex task. Previous research has indicated that these crashes occur because children are poorly trained in several aspects of pedestrian safety, quickly forget basic instructions, cannot accurately estimate the speed and distance of oncoming vehicles, and are easily overwhelmed by complex traffic situations. It was concluded that more practical training for children is necessary, utilizing familiar situations and locations. Research has also shown that parents often overestimate the cognitive capabilities of their children when faced with complex traffic situations, resulting in a premature lack of parental guidance during street-crossing situations. Recent studies indicate that 33 percent of untrained children do not search for vehicles prior to crossing unsignalized intersections. Also, approximately 95 percent of unattended children do not look behind for turning vehicles [McDonald, 2008].

The children in the mentioned age group have an overall understanding of danger but often they don't have the ability to determine the related or unrelated factors to road crossing and proper reaction while exposed to danger [Scottish Executive Social Reasearch, 2003]. Therefore, it is necessary to consider a certain procedure for schools safety and improve the traffic knowledge of students.

Traffic accident studies in Iran indicate that pedestrians are involved in about 40 percent of fatalities in rural areas (Recorded Accidents in Iran, 2006-2008). Meanwhile, according to the Iranian Legal Medicine Organization reports, about 29 percent of pedestrian fatalities were under 18 years old [Iranian Legal Medicine Org., 2007]. Considering the fact that approximately 2 million students live in rural areas and their schools are located near the roads, the aforementioned facts are pretty concerning. Referring to critical conditions of these schools and different parameters involved in accidents, it is essential to implement research on this issue. This paper presents a model for predicting students' accidents in the vicinity of rural roads which can be used in safety planning for rural schools. The paper structure is as follows: In the next section, a concise review on researches conducted about students and pedestrians is presented. The third section deals with the proposed methodology. The results analysis and model validation are presented in sections 4 and 5, respectively. Finally, conclusions on the research are briefly discussed in the last section.

2. Literature Review

So far, not many researches had been directly related to students' accidents. In this regard, Wedegama's studies in New Castle, UK, which offered a relationship between pedestrian accident and landuse utilizing 1998 to 2001 accident data, can be referred to. Wedegama acknowledged that different landuses –as a factor of trip attraction– are closely related to changes in pedestrians and bikers accidents. In spite of that, this study does not categorize pedestrians by age, sex and other groups, so that it is not possible to determine children accidents [Wedagama, 2006].

Seedris et al. (2005) determined that children accidents distribution rest upon their living environment, exposing some of them to higher risks. Using factors such as landuse, traffic parameters and social factors, they applied such criteria as educational condition, adjacent landuse condition and population density, as factors for predicting the number of pedestrian accidents [Wedagama, 2006].

Joly and colleagues, considering social and geographical variables, analyzed children accidents in Montreal, Canada. They claimed that areas with high number of pedestrian accidents have great similarity to areas with high rate of bikers' accidents [Joly et al., 1991]. Petch et al. argued that bikers/pedestrians accidents distribution cannot be carried out easily through analyzing a particular region, but it should be carried out locally and through special trip attraction centers [Christie, 1995].

Many other studies were performed on places with high possibility of children accidents. Some researchers investigated places in the vicinity of residential and roadside areas with high rate of accident. Finally, they all declared roadside areas as the major place of numerous children pedestrian accidents.

Larson stated that many children accidents take place in major or minor roads located in the vicinity of residential areas. In a study carried out in USA, it was determined that 33 percent of all children accidents happened in roads with speed limits more than 50 Km/h. Christie, Roberts et al. and Mouler et al. announced that in tangent sections of roads, the chance of children getting involved in accidents is higher. Jones and colleagues, in a study performed in two cities in UK, found traffic calming methods effective in reducing children traffic accidents [Jones et al., 2005].

Residential areas streets with high number of parked cars and high population density are announced as high risk areas for children. Sharplz and colleagues, according to their researches, expressed that the areas located within a 1-2 Km radius from school or home have high accident potential for children [Joly et al., 1991].

Studies also indicate that those children living in families with improper economic conditions are exposed to higher risk of accident. Many researchers [Graham et al. (2002], Perston (1992), Christie (1995), Koliz (2005)) stated that children accident occurrence has a reverse relationship with their economic conditions. Christie (1995), according to his researches, stated that accident fatalities in families with low income are four times more than families with high financial support. This might be due to less protection of children and lack of proper traffic knowledge of parents [Wedagama, 2006].

Some other researches [United Kingdom's Ministry of Transportation, 2000 and Duperrex et al. 2002] evaluated the effect of traffic safety education on children accidents, which their results confirmed positive outcomes of education on traffic accidents. On the other hand, Chen and colleagues studies (2005) showed that even those children aware of road dangers, due to underestimation of accident occurrence to themselves, are usually incapable of proper reaction in time. Duperrex et al. stated that though there is no evidence showing traffic accidents will be reduced if children take traffic safety trainings, but trainings should be repeated in order to change the behaviors and improve the traffic knowledge during the time [Duperrex et al., 2002].

3. Research Methodology

Accident Prediction Models (APMs) are widely used to estimate the frequency and/or severity of accidents for a given spatial unit over a certain period of time. One of the most important practical applications of APMs is site ranking (prioritization) which aims to identify high risk sites or locations with underlying safety problems. Site prioritization is also referred to as network screening; and sites with the potential for safety treatments are also known as accident black spots or hotspots in the literature [Wang et al., 2011].

Accidents are mutually exclusive events. In other words, an accident is in, and can only be in, one category of different severities (i.e. fatal, serious or slight). Such data, involving two types of discrete outcomes (i.e. count and discrete choice), can be modeled using a discrete multivariate model like Multi-Nomial Logit (MNL) and Probit [Geedipally and Turner, 2011; Savolainen et al., 2011].

Yamamoto and Shankar mentioned that MNL models have proper flexibility for calculation and prediction of accidents in comparison with similar models (Yamamoto and Shankar, 2004). Also, Savolainen and Mannering used MNL models for analyzing one and multi vehicle involving accidents and came to conclusion that factors such as age, type of accident, alcohol, wearing helmet and speeding can affect accident severities [Savolainen and Mannering, 2007].

The MNL model is particularly susceptible to correlation of unobserved effects from one accident frequency/severity level to the next. Such correlation causes a violation of the model's independence of irrelevant alternatives (IIA) property [Washington et al., 2011]. On the plus side, MNL models do not impose the sometimes unrealistic parameter restrictions that traditional ordered probability models do. Further, if the IIA property holds, it can be shown that in the presence of underreporting of crashes, all parameters will still be correctly estimated except for the constant term [Savolainen et al., 2011].

3.1 Model Structure

MNL models are based on observed choices made by individual units. To represent the attractiveness of the choices (alternatives), the concept of utility (which is a convenient theoretical construct defined as what the individual seeks to maximize) is used. Alternatives, per se, do not produce utility; this is derived from their characteristics and those of the individual. For example, the observable utility is usually defined as a linear combination of variables.

This model have some useful properties: the explanatory variables included in the model can have explicitly estimated coefficients. In principle, the utility function allows any number and specification of the explanatory variables, as opposed to the case of the generalized cost function in aggregate models which is generally limited and has several fixed parameters. Furthermore, MNL models allow a flexible representation of the policy variables considered relevant to the study; the coefficients of the explanatory variables have a direct marginal utility interpretation (i.e. they reflect the relative importance of each attribute).

The general form of utility function is as follows:

$$V_i = U_i + e_i \quad (1)$$

where:

V_i: random utility of choice i

U_i: deterministic component of i

e_i: random error term of i

The utility of each alternative to a specific decision maker can be expressed as a function of the observed attributes of the alternatives and the observed characteristics of the decision-maker. Once the distribution of the error term, e_i, is specified, the distribution of the utilities can be determined, and the choice function can be calculated explicitly.

Logit model, however, can be derived from the concepts of random utility and utility maximization by assuming that the random terms of each utility function are independently and identically distributed with a Gumbel (double exponential) distribution function [Ortuzar and Willumsen, 2011; Meyer and Miller, 2001; Kanafani, 1983].

There are different kinds of Logit Models which depend on the utility function and number of deciding alternatives. In case of selecting among several choices; MNL models can be applied for estimating the probability of selecting/happening each choice. The general structure of this model is as follows:

$$P_A = \frac{\exp\,(U_A)}{\sum_j (\exp\,(U_j))} \quad (2)$$

which:

P_A: probability of choice A

U_A: utility function of choice A

U_j: utility function of choice j

The utility functions usually include a set of parameters that are statistically estimated from observed choices.

For estimation of these models, the common and proper method is Maximum Likelihood Estimation (MLE). In this method, the primary approach is to maximize the goal function (Ben-Akiva and Lerman, 1993).

3.2 Model Variables

The dependent variable (number of accidents) is classified in three groups which are: Zero, 1 and 2 accidents in 1 year. The independent variables are such that account for traffic and geometric conditions. These variables are as follows:

a) 85th percentile speed (V85):

The 85th percentile speed is the speed at or below which at least 85 percent of the motorists drive on a given road unaffected by slower traffic or poor weather conditions. This speed indicates the speed that most motorists on the road consider safe and reasonable under ideal conditions. It is a good guideline for the appropriate speed limit of roads. By an increase in speed, the possibility of the pedestrian's death/injury in accidents will be increased exponentially. In this regard, researches indicated that the possibility of pedestrians' death when struck by a car moving with 65 Km/hr speed is 85 percent. This possibility is 45 percent if the car is moving 50 Km/hr and 5 percent if it moves 30 Km/hr.

b) Road width (Width):

Increasing the width of the road makes the pedestrian (students) cross longer distances and he/she would be more exposed to the danger of being struck by a car. It should be mentioned that road width means the distance that pedestrian should traverse in one stage. It means that in highways which the median is functioning as a refuge (with minimum 1.5 meter width), only the width of one side should be taken into account.

c) Number of students (Astudent):

The more the number of students, the more could be the risk associated with a school. This is due to increasing exposure of students to accidents as their number increase.

d) School guardian presence (Guardian):

According to the definition of the MOI (Ministry of Interior Affairs of IRI), guardian is a person or a student, who after being recognized and taking required courses and trainings, has the duty of guiding students while passing roads as well as encouraging them to obey laws and discipline. The presence of a trained guardian who is familiar with his/her duties could result in an increase in the safety of the students. The guardian variable is defined as a dummy variable in the model. Schools with guardians are coded as 1 and those without guardian are coded as 0.

e) Traffic-geometry content variable (ADT/Dis):

This variable, as a combination of traffic and geometric conditions, equals the ratio of the Average Daily Traffic (ADT) on a road in the vicinity of a school to the distance of the same school from the same road. It is logically expected that students will be exposed to more risk if this variable is high in quantity.

3.3 Data

A statistical sample was obtained from 122 cases of schools in the vicinity of rural roads in different provinces of Iran. Some of these schools were located near high traffic roads and some others were located near roads with less traffic. Table 1 shows the descriptive statistics of the variables used in students accidents modeling for this sample.

4. Results

Table 2 shows the correlation coefficients of variables and also the results of hypothesis test of each variable. As mentioned before, the accident variable is considered as the dependent variable. The results indicate

Table 1. Descriptive statistics of the model variables

	frequency	Range	Minimum	Maximum	Mean	Std. Dev.
Astudent	122	575	25	600	132.75	96.78
Width	122	9	7	16	10	2.332
V_{85}	122	57	67	124	90.83	12.341
Guardian	122	1	0	1	0.42	0.495
ADT/Dis	122	3986.58	13.41	4000	448	454.8
Accident	122	3	0	3	1.17	1.066

relatively good correlation between dependent and independent variables. Yet, the outcomes show weak correlation between guardian variable and the dependent variable. Also, the level of significance of the model variables was tested through hypothesis test. As it is shown, all variables are significant.

Table 3 shows the results of modeling the probability of occurring one accident per year. As it can be seen, all variables other than the dummy Guardian variable have direct relationship with the accident probability variable. The Guardian variable has negative coefficient which can be justified considering the negative effect of lack of school guardian (Guardian=0) in reducing the safety of students. In addition, the results of t student test are shown for each parameter. These results confirm the significance of the parameters in the model.

Table 4 indicates the marginal effect and elasticity of the variables. As seen, the marginal effect of Guardian is more than other variables. Following this variable, road width has the most marginal effect, as one unit increase in road width results in 0.01494 units increase in occurring 1 accident. Also, the results related to the elasticity of variables show that almost all variables are inelastic. In other words, 1 percent increase in these variables is less effective in the probability of

Table 2. Correlation coefficients of considered variables in students' accidents

Variable	Measure	A student	Width	V_{85}	Guardian	Accident	ADT/Dis
A student	Pearson Correlation	1	.424**	.336**	.026	.439**	.342**
	Sig. (2-tailed)		.000	.000	.048	.000	.000
Width	Pearson Correlation	.424**	1	.230*	-.100	.312**	.375**
	Sig. (2-tailed)	.000		.011	.025	.000	.000
V_{85}	Pearson Correlation	.336**	.230*	1	.290**	.331**	.434**
	Sig. (2-tailed)	.000	.011		.001	.000	.000
Guardian	Pearson Correlation	.026	-.100	.290**	1	-.067	.037
	Sig. (2-tailed)	.048	.025	.001		.041	.045
Accident	Pearson Correlation	.439**	.312**	.331**	-.067	1	.567**
	Sig. (2-tailed)	.000	.000	.000	. 041		.000
ADT/Dis	Pearson Correlation	.342**	.375**	.434**	.037	.567**	1
	Sig. (2-tailed)	.000	.000	.000	.045	.000	

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Table 3. Model results for the probability of 1 accident/year

Variable	Coefficients	t-test
Astudent	0.00251	1.995
Width	0.506	1.855
V_{85}	0.01547	1.908
Guardian	-0.3576	-2.813
ADT/Dis	0.01132	2.212

Table 4. Marginal effect and elasticity of variables for the probability of 1 accident/year

Variable	Marginal Effect	Elasticity
ADT/Dis	0.0003	0.32376
Width	0.01494	0.3645
V_{85}	0.00409	0.907
Guardian	-0.1399	-0.1426
Astudent	0.00059	0.1923

occurring 1 accident at schools located near roads.

Table 5 shows the results of estimation of occurring more than 2 accidents per year. Like the previous model, all variables except Guardian have a positive relationship with the dependent variable and their t tests show their significance.

Table 6 shows the marginal effect and elasticity of the model variables for the probability of 2 or more accidents per year. The results show that the marginal effect of Guardian is more than other parameters. Comparing with previous model, the parameters are more elastic. The variable "Width" has the most elasticity in comparison with other variables.

5. Model Validation

Table 7 shows the comparison between predicted accidents estimated by the proposed model and the real data. The results indicate that if the number of accidents is zero, 1 or equal or more than 2, model predicts correctly the probability of accidents 77.5, 70.7 and 78 percent, respectively.

Table 8 shows the measures for the validity of results.

For analyzing the difference between estimated and actual results, considering the numerical nature of accidents and in order to determine the validity of the models, Chi-square test has been used which is estimated as below (Navidi, 2010, Washington et al., 2011):

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - \varepsilon_i)^2}{\varepsilon_i} \tag{5}$$

where:

n: total observations

O_i: real observations

E_i: predicted value (Expected)

According to the hypothesis test, if $x^2 > x^2_{\alpha,\ k-1}$, it can be concluded that the null hypothesis H0 can be rejected by α percent probability. In this regard, considering Table 8 and comparing obtained value with x^2 (0.05,8), since [(-2)*(-104.301)>59.44] it can be stated that at the level of 0.05 there is no reason to reject H_0, and statistically, there is no difference in real data and predicted results. Hence, the outcomes presented by the model are valid.

Table 5. Model results for the probability of 2 or more accidents/year

Variable	Coefficients	t-test
Astudent	0.00579	4.625
Width	0.1115	2.179
V_{85}	0.00226	2.155
Guardian	-0.4593	-3.727
ADT/Dis	0.02139	3.901

Table 6. Marginal effect and elasticity of variables for the probability of 2 or more accidents/year

Variable	Marginal Effect	Elasticity
ADT/Dis	0.0097	1.1497
Width	0.0525	1.3812
V_{85}	0.0029	0.7032
Guardian	-0.1052	-0.1157
Astudent	0.00328	1.1439

Table 7. Comparison of model results and observations

Observed \ Predicted	0	1	2	Sum
0	31	7	2	40
1	5	29	7	41
2	3	6	32	41
Sum	39	42	41	122

Table 8. Evaluation criteria of the logit model for predicting student accidents in vicinity of roads

Measures	Chi squared	Significance level	Log-likelihood function
Values	59.44	0.0000	-104.301

6. Conclusion

In this study, a model for predicting students' accidents has been developed. The research approach was implementing discrete choice models, specifically multinomial logit model (MNL) for prediction of accidents. Considering the essence of discrete models, dependent variable (the number of accidents in schools located near roads) is divided into three groups of schools which were: No risk (no accident/year), low risk (1 accident/year) and high risk (two or more accidents/year). In order to form the utility function, variables such as road width, school guardian, functional speed, number of students and ADT/Dis (which was considered as a risk factor) were considered. Then the models were calibrated and the proposed models were able to predict the number and the discrete groups. Generally, most important results of this research are:

First, results show that the presence of Guardian in both of the presented models (1 accident and 2 or more accidents) is very effective. This issue can emphasize on implementing Guardian as a solution for enhancing the safety of students. As stated, children, especially in elementary schools are incapable to decide properly while facing traffic and presence of a trained person can be a great help to cross roads.

Second, road width, especially in the second model (2 or more accidents) is pretty important and is considered the most elastic variable. This indicates the importance of physical methods in immunizing roads and passages near schools in rural areas (e.g. constructing refuge islands, modifying medians, etc.) in order to give pedestrians more time to clear the roads.

Finally, the presented model is able to predict the occurrence of accidents with high accuracy (more than 70 percents). Therefore, it can be used as a useful tool for predicting the risks of schools and prioritizing the budget for traffic calming actions.

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