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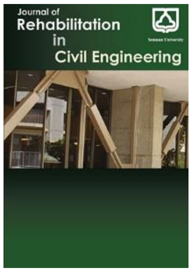

Modifying PIARC's Linear Model of Accident Severity Index to Identify Roads' Accident Prone Spots to Rehabilitate Pavements Considering Nonlinear Effects of the Traffic Volume

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ABSTRACT

Pavement rehabilitation could affect the accident severity index (ASI) since restoration measures means more safety for road users. No research or project has been carried out to identify hazard points to build a linear model based on crash severity index. One of the very popular accident severity index models used in all countries is based on linear models to rehabilitate pavements and this paper is aiming at correcting the deficiency of PIARC's related model i.e. lack of sensitivity to changes in the traffic volume flow, to modify crash severity index (which is based on linear models) making an allowance for the nonlinear effects of traffic on eventful locations on dual carriageways. To do so, traffic volume has been chosen as the hazard criteria and, using multiple regression and statistical models, the coefficients and variables of the new model have been calculated by means of the SPSS software. This study presents the structural defects for the correction of linear models based on the accident severity (sensitive to changes in traffic volume). This research provides a linear model based on the crash severity index considering the nonlinear effects of the traffic volume to identify roads main eventful locations. Recommended that the model for a comprehensive database of accident data be built for all other roads in order to enhance the research accuracy.

1. Introduction

Since the growing road network and increasing vehicles and speed leads to increased loss of life and financial losses consequence from road accidents. Improvement plans of the hazardous points are administrative priorities of any government. Investigation of influential factors on crashes enables engineers to carry out calculation in order to reduce crash severity. It is of an importance to investigate the effect of accident prone spots. Any investment in this area in order to improve these unsafe locations is the most feasible plan to be considered. The accident severity index measures the serious of an accident. It is defined as number of person depth per 100 accidents [1]. In recent decades, development of the roads network, growing number of vehicles and increasing speed have been the causes of increased fatalities and injuries; hence, prevention of financial losses due to road accidents and designing improvement plans to overcome danger created by hazardous points have become the government priorities [2].

One of the common methods of evaluating the accident severity index in this field is the linear method which identifies, according to the "World Road Association Guide", the risky locations on the roads network [3]. Often, modifying hazardous sites in terms of reducing accidents is a serious measure, and addressing the issue has the highest economic justification. Studies on the effects of road geometry and traffic volumes on rural roadway accident rates show that although the importance of isolated variables differs between two-lane and multilane roads, ‘geometric design’ variables and ‘pavement condition’ variables are the two most important factors affecting accident rates) [4]. This paper is aiming at correcting the defect of PIARC’s accident severity index linear model to identify roads' main eventful locations through considering the nonlinear effects of the traffic volume.

2. Research Method

This research was carried out with, first, selecting model variables and study areas, then obtaining statistical information and next checking the quality and quantity of the statistical investigated samples.

Information required for the research model variables was obtained on Tehran-Amol (Haraz) and Karaj-Chalous roads in Iran, and the traffic volume data along these axes was acquired from the Ministry of Road and Transportation [5]. Analyses of multiple regressions on the generated statistical data were carried out using the SPSS software [6]. The model was built and its variables and coefficients were determined.

3. Linear models' overall pattern based on the crash severity

The PIARC linear model is based on the crash severity and is consistent with the following relation:

$$I=b1x1+b2x2+b3x3 \qquad (1)$$

where x1=damage accident, x2 =injury accident, x3= fatal accident, I=hazard index and b1, b2 & b3 are some constant coefficients.

4. Quality control of the critical accident severity rate

In this study, to determine the traffic volume use has been made of the critical severity rate of accidents (equation 2) as a dependent variable [7].

The critical severity rate of accidents (Rc) for each desired road category in terms of millions of vehicles passing during the study period is calculated as follows:

$$\mathrm{Rc} = \mathrm{Ra} + \mathrm{K}\sqrt{\frac{\mathrm{Ra}}{\mathrm{m}} - \frac{0.5}{\mathrm{m}}} \qquad (2)$$

Where

$$\mathrm{Ra} = (P\times1000000) / [(ADT\times1036] \qquad (3)$$

is the average rate of accidents severity on the road system for a desired road category in terms of millions of vehicles passing, K is a constant = 1.645 for a 95% confidence level, m is the No. of vehicles passing the point under study (in millions) found as follows:

$$\mathrm{m} = \frac{\mathrm{ADT}\times\ (\text{No. of days during the study})}{1000\,000}$$

(4)

1036 is No. of days of the study period, AD T is the average daily traffic, P is the accident severity rate (here, coefficients b1, b2 and b3 are equal to 0.5, 3, and 9 respectively).

We selected 118 sections on Karaj-Chalus and 48 on Tehran-Amol (Haraz) carriageways (length of a section=1 km). Tables1 and 2 shows observations of the independent variables and the dependent variable (Rc).

The model making process was based on the quality control of (Rc) which was used as the dependent variable observations. In other words, such independent variables as damage, injury and fatal accidents were placed together in a linear form; hence, instead of placing the linear alignment of the traffic volume (as an independent variable) along with other variables, the impact of traffic volume was considered as the dependent variable in nonlinear observations. The volume of traffic as a nonlinear coefficient in the linear model was, in fact, influential.

In Table 1 and 2, ADT is the Average Daily Traffic for 1036 days, and N is the No. of points representing a distance of 1 km each.

Table 1. Data from Karaj-Chalus Road [5]

N	Damage	Injury	Fetal	RC	ADT	N	Damage	Injury	Fetal	RC	ADT
1	278	15	2	8.65	25059	60	18	5	1	2.91	13723
2	28	1	2	1.65	25059	61	22	0	0	1.00	13723
3	64	22	1	4.76	24950	62	25	0	0	1.15	13723
4	126	10	1	4.55	24950	63	10	4	1	2.33	13723
5	152	9	3	5.86	24350	64	26	2	0	1.74	13723
6	68	4	0	2.21	24200	65	5	3	0	1.05	13723
7	151	2	0	3.78	24300	66	30	1	0	1.65	13723
8	13	2	0	0.63	19300	67	32	2	0	1.99	13723
9	81	14	6	6.80	21980	68	36	15	0	5.3	13723
10	218	5	2	7.06	21980	69	37	1	0	1.95	13723
11	149	8	3	6.28	21980	70	7	3	0	1.15	13723
12	133	2	1	4.18	21980	71	39	0	0	2	13783
13	255	13	2	9.05	21980	72	40	3	0	3	13783
14	23	1	1	1.28	21980	73	43	0	1	3	13783
15	170	11	4	7.63	21980	74	44	0	0	2	13783
16	33	4	4	3.36	21980	75	45	1	0	3	13783
17	54	21	0	4.59	21980	76	46	1	0	2	13783
18	23	0	1	1.12	21980	77	48	0	0	2	13783
19	227	11	0	7.27	21980	78	15	1	1	2	13783
20	201	24	0	8.61	21670	79	19	6	0	2	13783
21	63	4	3	3.76	21350	80	22	7	0	4	13783
22	58	5	1	2.88	21350	81	16	2	2	1	13783
23	49	4	0	2.02	21400	82	19	2	0	3	13783
24	66	8	1	3.53	21400	83	24	0	4	1	13783
25	76	1	1	2.76	21070	84	28	3	0	5	13783
26	31	5	0	1.73	21070	85	29	1	0	2	13783
27	192	7	4	7.91	21070	86	21	7	0	3	13783
28	225	6	1	7.26	2140	87	9	2	1	1	13783
29	22	9	1	2.61	21000	88	14	0	0	1	13783
30	26	7	0	1.92	21100	89	20	0	0	1	13783
31	77	10	0	3.78	20700	90	11	1	2	1	13783
32	89	3	0	2.99	20750	91	31	3	0	4	13783
33	67	6	7	6.12	20700	92	12	2	1	1	13783
34	159	3	1	5.57	19570	93	17	1	0	2	13783
35	25	10	1	3.07	19500	94	43	0	0	2	13783
36	29	2	0	1.30	19200	95	33	2	0	2	13783
37	43	4	3	3.63	19200	96	37	2	0	2	13783
38	14	7	0	1.76	19200	97	17	4	1	2	13783
39	21	6	0	1.94	17800	98	20	0	0	2	13783
40	31	0	0	1.06	17800	99	14	2	0	1	13783
41	29	1	0	1.21	17700	100	28	1	0	2	13783
42	16	2	0	0.99	17200	101	141	3	0	7	13783
43	28	0	0	1.08	16050	102	36	0	2	2	13783
44	26	5	0	2.12	16050	103	29	1	1	3	13783
45	69	0	0	2.58	16050	104	25	0	0	2	13783
46	41	8	0	3.33	15760	105	26	5	0	3	13783

47	172	1	0	6.36	15760	106	5	0	0	0	13783
48	80	7	0	5.14	15760	107	26	3	0	2	13783
49	111	2	1	5.88	13723	108	37	3	0	2	13783
50	24	0	1	1.91	13723	109	58	0	0	3	13783
51	37	0	2	3.19	13723	110	20	5	3	4	13783
52	19	4	0	1.95	13723	111	81	2	0	4	13783
53	25	0	0	1.15	13723	112	3	4	1	2	13783
54	21	3	0	1.78	13723	113	6	9	0	3	13783
55	18	1	0	1.10	13723	114	69	2	0	4	13783
56	26	4	1	2.99	13723	115	13	4	3	4	13783
57	15	5	0	2.04	13723	116	16	0	2	2	13783
58	17	1	2	2.62	13723	117	42	1	0	2	13783
59	13	2	0	1.15	13723	118	39	2	1	4	13783

Table 2. Data from Tehran-Amol (Haraz) Road [5]

N	Damage	Injury	Fetal	RC	ADT	N	Damage	Injury	Fetal	RC	ADT
1	9	2	2	2.54	13723	25	212	17	2	7.55	21070
2	8	0	0	0.28	13723	26	83	29	1	6.00	25060
3	4	0	1	1.00	13723	27	23	0	0	0.44	25060
4	21	10	0	3.52	13723	28	29	1	0	0.81	25060
5	28	11	5	7.54	13723	29	48	5	1	2.24	24900
6	60	5	0	3.88	13723	30	73	10	2	3.86	24600
7	77	0	0	3.36	13723	31	116	9	0	3.93	24300
8	11	7	0	2.37	13723	32	29	0	0	1.33	13723
9	55	24	3	10.2	21980	33	61	4	0	3.68	13723
10	51	0	0	2.29	21980	34	30	1	0	1.65	13723
11	2	1	3	2.75	21350	35	18	1	0	1.10	13723
12	115	11	0	4.62	21350	36	341	39	8	27.5	13723
13	23	1	0	0.76	21350	37	19	0	0	0.09	13723
14	63	4	2	3.31	21350	38	161	1	0	6.88	13723
15	58	5	1	2.88	21350	39	21	19	0	5.65	13723
16	49	6	0	2.34	21350	40	102	0	0	4.35	13723
17	66	3	0	2.31	21070	41	276	4	0	11.9	13723
18	76	8	1	3.84	21070	42	24	3	3	4.12	13723
19	144	12	2	6.58	21070	43	77	29	7	3.14	64300
20	81	16	1	4.95	21070	44	148	12	2	5.90	23820
21	149	14	2	6.71	21070	45	147	74	1	5.97	53700
22	133	17	1	6.33	21070	46	249	31	5	11.90	23380
23	34	1	0	0.91	21070	47	178	54	4	8.84	34280
24	18	0	0	0.35	21070	48	671	23	9	22.3	22540

4.1. Quality control tests and the sample size

4.1.1. Kayrez, Maier, and Oklin (KMO) test

Kaiser-Meyer-Olkin (KMO) Test is a measure of how data suited for **Factor Analysis**. The test measures sampling adequacy for each variable in the model and for the complete model. The statistic is a measure of the proportion of variance among variables that might be common variance. The lower the proportion, the more suited your data is to Factor Analysis.

Sample size sufficiency was investigated using KMO test (Table 3); with KMO index > 0.6 and significance level < 0.05 the sample size was sufficient [8].

4.1.2. Factor analysis test

To investigate the validity of the test variables and samples, use was made of the factor analysis test (table 4).

Table 3. KMO test results

KMO index	0.677
Bartlett test	96.041
Degree of freedom	3
Significance level	0.000

Table 4. Factor analysis test results

Damage accident	0.736
Injury accident	0.638
Fatal accident	0.664

According to Table 3, KMO index=0.677 > 0.6 and significance level=0.000 < 0.05 (both are OK), and according to Table 4, coefficients of the factor analysis for all variables are approximately 0.7 (data is applicable).

4.1.3. Durbin–Watson test

If the Durbin-Watson data range is 1.5-2.5, the error independence assumption is acceptable; according to Table 5, Durbin–Watson statistic=1.658 which is acceptable [9].

Table 5. Durbin - Watson test result

Correlation coefficient(R)	Coefficient of determination	Adjusted correlation coefficient	Estimated standard deviation	Durbin-Watson Statistic
0.916[a]	0.839	0.836	1.34347	1.658

4.1.4. Regression coefficients test

Table 6. Regression coefficients

Model	Independent variable coefficients (B)	Correlation coefficient (Beta)	T	Significant relationship
Constant	0.892		6.413	0.000
Damage accident	0.027	0.640	16.695	0.000
Injury accident	0.063	0.178	4.825	0.000
Fatal accident	0.560	0.275	7.366	0.000

According to table 6, variable coefficients are as follows:

Damage accident =0.027

Injury accident =0.063

Fatal accident =0.056

5. Model structure

On the basis of linear regression formula: $y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n$ (5)

where b_0 is the intercept, $b_1=x_1$ (variable coefficient)

Based on the coefficients acquired, the final model is obtained as follows:

$$Y=0.892+0.027x_1+0.063x_2+0.560x_3 \qquad (6)$$

where

X_1=damage accident, X_2 =injury accident, X_3 =fatal accident, and Y = hazard rate

5.1. Model Assessment

According to table 7, variables with partial correlation coefficients (Beta) in regression testing are as follows:

• The impacts of damage, injury, and fatal accidents on the construction of the road model are equal to 64, 17.8, and 27.5% respectively. Since significance levels for all the coefficients obtained for the model shown in Table 7, were less than 0.05%, they were accepted.

Table 7. Correlation between variables

Model		Model output	Damage accidents	Injury accidents	fatal accidents
Pearson Correlation coefficient	Model **o**utput	1.000	.859	.596	.664
	Damage accidents	.859	1.000	.470	.498
	Injury accidents	.596	.470	1.000	.424
	Fatal accidents	.664	.498	.424	1.000
(Level of significance)	Model **o**utput	.	.000	.000	.000
	Damage accidents	.000	.	.000	.000
	Injury accidents	.000	.000	.	.000
	Fatal accidents	.000	.000	.000	.
Total	Model **o**utput	166	166	166	166
	Damage accidents	166	166	166	166
	Injury accidents	166	166	166	166
	Fatal accidents	166	166	166	166

Following are the results drawn from Table 7:

Table 8. Summary of the results of Table 7

Correlation			Coefficient	Standard	Acceptance
Accident damage	v	Injury accidents	0.470	>0.5	OK
Accident injury	v	Fatal accidents	0.424	>0.5	OK
Accident damage	v	Fatal accidents	0.498	>0.5	OK
Accident damage	v	Y	0.859	>0. 3	OK
Accident injury	v	Y	0.596	>0.3	OK
Fatal injury	v	Y	0.664	>0.3	OK

Table 9. Summary of the results of regression models

Correlation coefficient (R)	Coefficient of determination	Adjusted correlation coefficient	Estimated standard deviation
0.916[a]	0.839	0.836	1.34347

Table10. ANOVA regression result

Pattern	Sum of squares error	Degree of freedom	Mean square error	F-statistic	Level of significance
Total regressions	1520.938	3	506.979	280.889	.000a
	292.396	162	1.805		
	1813.334	165			

Since all the significance levels shown in Tables 7 and 8 are less than 0.05, the correlations obtained are accepted. A summary of the results of regression models is shown in Table 9.

According to Table 9, the model coefficient is 0.839 which shows validity of the model.

In this paper Analysis of variance (ANOVA) has been used. (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures (such as "variation" among and between groups. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. It is conceptually similar to multiple two-sample t-tests, but is more conservative (results in less type I error) and is therefore suited to a wide range of practical problems [10]. Table 10 presents the ANOVA regression model wherein a significance level less than 0.05 confirm the model validity.

5.2. Determination of events changing ranges

Using the statistics in Table 10, following information is obtained.

Table11. Statistics

Mean	3.9874	Variance	10.990
Median	2.5812	Range	27.28
Mod	1.10a	Min	0.18
Standard deviation	3.31510	Max	27.46

Table12. Hazard rate evaluation

Hazard rate in four intervals		
25%	50%	75%
1.73	2.58	٤,٤4

According to Table 12:

- 25% of samples have hazard rate of less than 1.73.
- 50% of samples have hazard rate of less than 2.58.
- 75% of samples have hazard rate of less than 4.44.
- Values below 1.73 show low risk locations.
- Values between 1.73 and 2.58 show medium risk locations.
- Values between 2.58 and 4.44 show high risk locations.
- Values higher than 4.44 show very high risk locations.

Also, rate of accident-prone spots in 10 strata can be analyzed from Table 13.

Table13. Conditions of the research output strata

Stratum	Output
10	1.0606
20	1.3889
25	1.7342
30	1.9099
40	2.1974
50	2.5812
60	3.1509
70	3.8580
75	4.4427
80	5.2338
90	6.9376

6. Results

The following results have been obtained after implementing and evaluating the model:

1- This study presents the structural defects for the correction of linear models based on the accident severity (sensitive to changes in traffic volume).

2- It provides a linear model based on the crash severity index considering the nonlinear effects of the traffic volume to identify roads main eventful locations.

3- Given that these results are available (based on the data analyses carried out in this study), it is recommended that the model for a comprehensive database of accident data be built for all other roads in order to enhance the research accuracy.

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