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Effects of road geometric parameters on safety: A case study of Mugling-Narayanghat road in Nepal

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Abstract

Road safety has emerged as a global priority due to the multifaceted consequences of road traffic accidents (RTAs) in modern society. The study is focused on the development of an accident prediction model (APM) and identifying the influence of geometric factors on road safety. The study section of the highway was divided into 190 identical segments based on geometric characteristics. Eight models have been developed for establishing the relationship between crash numbers and respective parameters. The significance of

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the models has been validated by the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The study unveils that the shoulder and lane width, numbers, and radius of the horizontal curve significantly influence RTAs. However, the gradient and shoulder type have less impact on road accident frequency. The research recommendations for the improvement of safety are increasing the radius of the curves, lane, and shoulder width. Similarly, the study suggests the reduction of the number of horizontal curves for the reduction of crash frequency.

Subject Classification: *15A06, 62P25, 62P30.*

Keywords: *Accident prediction, Geometric design, Road safety, Safety performance.*

1. Introduction

Transportation is a key element of the country's development issue, affecting practically every aspect of mobility [28]. The progress of the overall level of transportation necessitates the coordinated development of different sectors jointly for the advancement of the transportation system [9]. Road transportation is a fast-growing industry in developing countries, but it raises the risk of traffic accidents [18]. An accident is a traumatic and sudden event that affects both victims and their families [24]. RTA is currently the 8th major cause of fatalities in the glove, and increasing death rates indicate that it will be the 5th major cause by 2030 [36]. Globally, road safety is a major socioeconomic issue [10]. More than 1.35 million people are murdered and nearly 50 million are wounded in RTAs every year. "Developing nations are responsible for more than 90% of all fatalities. Over 2,000 people in Asia-Pacific are killed in road accidents every day, with one person dying every 40 seconds with significant economic consequences" [36]. Thus, the negative impact of RTAs cannot be ignored [34]. "RTAs must be regarded as an issue that needs to be handled as soon as possible to mitigate the health, social, and economic benefits" [20]. Improved road infrastructure design, as well as the incorporation of safety measures into road planning and design, are critical for lowering accident rates [32].

"An APM is included in the Highway Safety Manual (HSM) for forecasting yearly accident numbers based on severity, facility type, and incidence type" [1]. APM was developed by the HSM using crash data and road geometric features from specific states of the United States of America and the number of crashes under specific primary conditions [5]. APMs are immensely powerful techniques that are employed in managing road traffic safety (RTS) because they can determine both the number and severity of RTAs [25]. Nepal is a South Asian country with a low per capita income. It has over 15.9 fatalities per 100,000 people and an accident rate of 17 per 10,000 vehicles, which is higher compared to other Southeast Asian countries [36]. APM development for rural highways is a burning issue for developing nations like Nepal because it is a significant predictor of crashes, fatalities, and injuries [12]. "APMs have proven to be an effective tool for analyzing traffic safety through risk factor evaluations, identifying critical areas, and monitoring safety results" [11].

Different risk factors related to driver characteristics, vehicular factors, roadway factors, and environmental factors are associated with the severity of an accident [35]. Significant progress has been achieved in accident predicting modeling, however, more study is needed [39]. Similarly, significant improvements in road safety have been achieved by improving hazardous road geometric features [33]. The study of risk factors and their mitigation is a hot topic in traffic safety research [27]. Most countries are focused on enhancing traffic safety and lowering the intensity of road accidents. RTAs have become a major social issue in Nepal, and the scenario is worsening daily. The current road infrastructure is insufficient and inadequate with growing urbanization and industrialization. As a result, to improve road safety, appropriate traffic safety enhancement initiatives must be performed for high-accident roadways. Therefore, the researchers planned to investigate road geometric parameters from the perspective of road safety.

2. Literature Review

A road traffic accident occurs when at least one moving vehicle collides on a public road, causing material damage, injury, or death [17]. The enormous increase in traffic accidents poses social and economic issues to nations, particularly emerging ones, and has resulted in a high number of fatalities and injuries [21]. "Accidents are caused by several factors, including geometric, environmental, and traffic factors" [15].

Road Geometric Factors

The link between RTAs and road geometric design elements must be identified for safer road design [16]. "Shoulder width, number of lanes, lane width, shoulder type, median, horizontal alignment, and vertical alignment are all critical factors in determining road safety" [8]. Road engineering parameters are the important factors that influence the frequency and severity of road crashes [3].

Lane Width

Lane width is associated with driving comfort and the accident rate. According to Mclean (1995), lane widths of 3.4 m to 3.7 m are responsible for lower accident rates [22]. Another study concluded that increasing the width of the lane from 2.75 to 3.36 meters minimizes the possibility of accidents by 50% [38].

Shoulder Width

Different studies have found that shoulder width has an impact on roadway accident rates. In terms of road conditions, lane width is linked to shoulder width [26]. Shoulder widths ranging from 0.9 to 2.7 m are responsible for a 20% reduction in accidents [22]. From a road safety viewpoint, the most suitable shoulder width proposed by them is 1.5m. Shoulder widths less than 2 m are less likely to be involved in accidents than shoulder widths greater than 2 m [14].

Number of Lanes

Deo (2004) conducted a study and discovered an association between the number of lanes and RTAs [6]. According to Noland and Oh (2004), RTAs are significantly correlated with the number of lanes [26].

Horizontal Curve

A horizontal curve is an important geometric factor influencing fatal and injury accidents [37]. "Roads with many curves have a higher accident rate than roads with fewer curves" [23]. The number of crashes inclined as the curve radius declined [36]. Similarly, the United Kingdom's Department of Transportation (1984) discovered a major increase in accident rates as the curve radius decreased [7]. According to several studies, roads having a radius of curve less than 200 m increase accidents significantly [10]. Another important engineering parameter to be considered when designing a road network is the road gradient. Accidents are more common on roads with steep gradients [30].

3. Materials and Methods

The selected Mugling to Narayanghat two-lane rural highway section is 36 kilometers (22.37 miles) long. It is divided into 190 identical segments in such a way that at least one road geometric parameter such as shoulder type, lane width, horizontal curve, shoulder width, and gradient changed a new homogenous segment starts.

Data Collection

Road geometric data were collected from the records of the Department of Road and field surveys. The information contained in these records included road segment length, vertical grades, horizontal curvature, and cross-sectional elements. The Nepal traffic police provided three years of crash data from 2016 to 2018.

Modeling Procedure

The APMs were created using GLMs with negative binomial regression. "Negative binomial regression is the most effective model for analyzing traffic accidents" [30]. Road safety decision-makers frequently use GLMs to identify transportation safety risk factors [13]. R statistical software was used for the analysis. The segment length (kilometers), lane width (feet), shoulder type, shoulder width (m), gradient, curve radius, and the number of horizontal curves were the independent variables in this research. The basic regression equation is as follows:

$$N_{\text{Predicted}} = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \ldots \alpha_n x_n \tag{1}$$

Where,

$N_{\text{Predicted}}$ = Predicted crash, α_0 = Intercept, α_1, α_2, α_n = Coefficients, x_1 to x_n = Geometric features of road

Model Validation

Akaike Information Criterion (AIC)

Based on AIC, developed models were compared. "Hirotugu Akaike invented this test in 1971" [4]. The lower a model's AIC value, the better the model fits.

$$\text{AIC} = -2\log\text{L}+2\text{p} \tag{2}$$

Where, log L = Maximum log-likelihood, p = Independent variables

Bayesian Information Criterion (BIC)

"The BIC test was used to compare the developed models. Schwarz developed this test as shown in the equation below" [29]. For better model fit the value of BIC should be lower.

$$BIC = -2\log L + S\ln(n) \tag{3}$$

Where, S= Independent variable, n = Sample size

4. Result and Discussion

Table 1 illustrates the descriptive statistics for the research variables. The average 3-year accident rate is 1.21, with a standard deviation of 1.87, indicating a minor over-dispersion of collision data. Similarly, the average 3-year average annual daily traffic (AADT) is 9048, with an average segment length of 0.170 km. Likewise, the average width of the shoulder is 0.340 m. The widest segment is 1.50 m and the narrowest is zero meters.

Table 1

Descriptive Statistics of Study Variables

List of Variables	Values	N	Min.	Max.	M	SD
Average 3 years accidents	2016 to 2018	190	0	9	1.21	1.87
Average AADT	2016 to 2018	190	9048	9048	9048	
Number of segments		190	1	190	95.5	94.9
Length of a segment (km)		190	0.1	0.6	0.17	0.09
Shoulder width (m)	>1	190	0	1	0.34	0.48
	<1	190	0	1	0.66	0.48
Lane width (ft)	9	190	0	1	0.29	0.46
	10	190	0	1	0.70	0.46
Shoulder type		190	0	1	0.07	0.26
Vertical curve grade	<3%	190	0	1	0.47	0.50
	3% to 6%	190	0	2	0.34	0.48
	>6%	190	0	1	0.19	0.40
Horizontal Curve radius (m)	Less than 250	190	0	3	0.65	0.51
	250 to 500	190	0	1	0.13	0.34
	500 to 750	190	0	1	0.06	0.24
Horizontal curves number		190	0	3	0.87	0.56

Note: SD= Standard deviation, N= Segment number, M=Mean

Model Test Parameters

Various road geometric parameters are analyzed by using R studio to identify the most critical geometric factors. Table 2 displays the coefficients of regression for each variable as per the best-fitted model including incident rate ratio (IRR), BIC, and AIC. The intercept coefficient of the statistically significant model is 1.17 at the 0.05 level of significance. This result reveals that the value of standard error is not equal to zero and the significance level was set at 0.02001 which is less than 0.05. According to findings shoulder, and lane width is positively related to the RTAs having significant values of 0.002460, and 4.87e-06 respectively.

Table 2

Goodness of Fit (GOF) Measure

M	Variables	Coefficient	P Value	IRR	BIC	AIC	2LL
1	$N_{Predicted} = \alpha_0 + \alpha_1 \ln(L) + \alpha_2 LW_9$						
	Intercept	0.638	0.2038	2.11	574.6	561.6	-553.6
	Ln L	0.404	0.1164				
	LW_9	0.750	0.0026 **				
2	$N_{Predicted} = \alpha_0 + \alpha_1 \ln(L) + \alpha_2 SW_1$						
	Constant	1.544	0.0024 **	0.28	563.5	550.5	-542.5
	Ln L	0.585	0.0230 *				
	SW_1	-1.263	4.67e-06 ***				
3	$N_{Predicted} = \alpha_0 + \alpha_1 \ln(L) + \alpha_2 GV_1 + \alpha_3 GV_2 + \alpha_4 GV_3$						
	Intercept	-0.082	0.959	2.64 2.96 3.31	592.9	573.4	-561.4
	Ln L	0.439	0.098				
	GV_1	0.973	0.528				
	GV_2	1.087	0.466				
	GV_3	1.197	0.442				
4	$N_{Predicted} = \alpha_0 + \alpha_1 \ln(L) + \alpha_2 RHC_1 + \alpha_3 RHC_2 + \alpha_4 RHC_3$						
	Intercept	0.402	0.450	2.23 2.22 1.35	588.5	569.0	-557.0
	Ln L	0.500	0.060				
	RHC_1	0.806	0.006 **				
	RHC_2	0.798	0.006 **				
	RHC_3	0.301	0.661				

Contd...

5	$N_{Predicted} = \alpha_0 + \alpha_1 \text{In (L)} + \alpha_2 ST$						
	Intercept	0.997	0.045 *				
	Ln L	0.419	0.111	0.36	580.6	567.6	-559.6
	ST	-0.999	0.075				
6	$N_{Predicted} = \alpha_0 + \alpha_1 \text{In (L)} + \alpha_2 NHC$						
	Intercept	0.343	0.514				
	Ln L	0.401	0.125	1.82	564.8	577.7	-556.8
	NHC	0.603	0.005 **				
7	$N_{Predicted} = \alpha_0 + \alpha_1 \text{In (L)} + \alpha_2 SW_1 + \alpha_3 LW_9 + \alpha_4 NHC + \alpha_5 RHC_1 + \alpha_6 RHC_2$						
	Intercept	0.653	0.2805	0.34 2.03 1.27 1.23 1.20	573.6	547.6	-531.6
	Ln L	0.501	0.0426 *				
	SW_1	-1.052	0.0004 ***				
	LW_9	0.708	0.002**				
	NHC	0.245	0.260				
	RHC_1	0.214	0.468				
	RHC_2	0.182	0.635				
8	$N_{Predicted} = \alpha_0 + \alpha_1 \text{In (L)} + \alpha_2 SW_1 + \alpha_3 LW_9$						
	Intercept	1.169	0.0200 *				
	Ln L	0.531	0.0328 *	0.29 2.00	559.8	543.6	-533.6
	SW_1	-1.230	4.87e-06 ***				
	LW_9	0.695	0.0024 **				

Significance codes: 0 '***', 0.001 '**', 0.01 '*'. 0.05 '.', 0.1 **Note:** M=Model, LL=Log Likelihood

GOF of the Developed Models

Crashes, segment length, shoulder width, shoulder type, lane width, horizontal curves number, gradient, and curve radius were considered for model development. BIC and AIC values were used to appraise the model. Out of the developed models, model 8 has the lowest estimated BIC and AIC values followed by model 2. The geometric features that fit the best were lane and shoulder width. These variables are significantly correlated with RTAs and vice versa. The lane width of model 1, has a positive relationship with accident frequency. Likewise, in model 2, shoulder width is positively associated with the RTAs.

Influence of Shoulder Width on RTAs

As shown in Table 2 shoulder width has a significant impact on accident frequency. Further, as shoulder width increases, the average number of crashes decreases. A shoulder width greater than one meter reduces the accident by 29%.

Influence of Lane Width on RTAs

Lane widths were classified into two groups as per width ranges. The control group was the standard case (12ft). IRR was calculated as a log ratio of the variables. From the analysis, the IRR of a 9 ft lane width is exp (0.750). It shows that a 9 ft lane width has a 111% more possibility of causing an accident compared to a 12 ft. This indicates that as lane width is reduced, RTAs increase dramatically. A wider lane allows drivers to obtain more space to correct potential errors and helps to avoid accidents.

Influence of Curve on RTAs

Highways with a curved radius of 500 to 750 m have a 35% higher chance of colliding. On the other hand, the radius of the horizontal curve of less than 500 m increases the chance of an accident by 122%. In a curve, the radius is an important factor and as the radius of the horizontal curve decreases, RTAs increase [37]. It demonstrates with a 95% confidence level that the variable is significant and that curve density influences RTAs. Similarly, our findings revealed that the number of curves on rural highways has a significant impact on crash frequency.

"Several studies have found a strong relationship between RTAs and curve density. Lane width is the most important factor in accidents, followed by curve length, traffic volume, curve radius, and curve type" [31]. A study conducted in Korea by Khedher and Yun (2022) on the impact of road geometric design features on crash frequency in rural roads revealed that road barriers, shoulder width, and AADT are significantly associated with road safety [19]. Another study, conducted to examine the effect of road geometric layout on traffic accidents, discovered that straight road geometrics have a high number of traffic accidents. Furthermore, road horizontal curved geometry has a statistically significant and positive effect on traffic fatalities [40]. The use of reliability-based analysis in roadway geometric design improves traffic safety significantly [2].

5. Conclusions

RTAs on Nepal's highways are steadily increasing causing massive socioeconomic losses. To reduce RTAs, it is vital to understand the link between crash frequency and road geometric characteristics. For this several models were created to determine the impact of roadway geometric parameters on road safety. Variables investigated for APM development were segment length, shoulder type, shoulder width, lane width, gradient, curve density, and curve radius. According to the study's findings, lane and shoulder width of highways are the statistically significant and most influential parameters for crash occurrence and are considered in APM development. The BIC and AIC tests were employed to evaluate the developed models. Shoulder widths of more than one meter reduce RTAs by 29% ($e^{-1.23} = 0.29$), whereas lane widths of less than nine feet ($e^{0.695} = 2$) double the number of accidents. Finally, we concluded that shoulder and lane width are important geometric factors to consider when developing an APM for rural highways. Similarly, a wide shoulder increases the number of accidents; thus, when designing rural highways, planners should consider roadways with 1 to 2 m of shoulder width and lane width greater than 3 m.

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