International Journal of Research in Engineering, Science and Management
Volume-2, Issue-11, November-2019
www.ijresm.com | ISSN (Online): 2581-5792

V_{85}th Speed Prediction Model on Horizontal Curve of Two-Lane Highway: A Case Study of Naubise – Naghdunga Road

Rajesh Dhakal[1], Anil Marsani[2]
[1]*M.Sc. Student, Department of Civil Engineering, Pulchowk Engineering Campus, Kathmandu, Nepal*
[2]*Assistant Professor, Department of Civil Engineering, Pulchowk Engineering Campus, Kathmandu, Nepal*

Abstract*: Consistency of design refers to the conformance of the highway's geometry to driver expectancy. Drivers make fewer error in the vicinity of the geometric features that conform to their expectation. A technique to evaluate the consistency tool require the ability to accurately predict speed as a function of roadway geometry. In this research paper a several efforts were undertaken to predict operating speed for different geometric features on the road. Operating speed models need to be developed to understand how traffic control and geometric features affect drivers speed selection. This study aims to develop operating speed prediction models for horizontal curves on rural two-lane undivided highway using 37 horizontal curves sections. The data analysis showed that operating speed in each curve varies with the geometrics features in that section. For this Speed prediction models (SPMs) have been used as a useful planning and design tool in many developed countries for the management of traffic in highways. Though many studies have been carried out in many countries in different approach, the speed model differ from one place to another in many ways as per site geometric features. Therefore, research gaps remain regarding the identification of factors associated with the operating speed in highways of Nepal. The main objective of this study is to develop suitable models for the speed prediction for the rural highways of Nepal. A mathematical model derived based on the existing geometrical features with observed speed on that horizontal curve and shows that radius, deflection curve, length of curve and gradient are significant for V85th operating speed.

***Keywords*: Multi-Linear Regression, operational Speed, Geometric parameters, horizontal curve, Accident.**

1. Introduction

Speed is defined as one of the most important factors that road users consider to evaluate the convenience and efficiency of a route. The number of traffic jams and crashes in Nepal increases relatively from year to year, although there are many programed organized by the authority to reduce them. There are several factors that lead to serious crashes of which majority of accident occur in horizontal curve on the National highway road. One of the traffic survey published on Nagdhunga-Naubise road shows that One thousand and twelve accidents were reported on Naubise–Nagdunga road over the study period with 3.6 accidents/km per year out of total accident 446 were recorded in 2011 where 546 accidents in 2012 involving a total of 1,383 vehicles (Nepal Traffic Police Headquarter, Singhadurbar). Among the vehicles involved in accidents, truck and tripper were at the top position (27%), followed by two wheelers (25%) which are indeed caused by human behavior, vehicles condition, weather condition, road surface and road alignments (vertical and horizontal curves) etc. Hence operating speed models should be introduced on behalf of traditional speed design models which need to be developed to gain an understanding of how geometric features affect drivers' speed selection. Once it is known how drivers choose their speed, roadways can be designed to maintain consistency by matching geometric features with drivers' expectations. The operating speed is the speed drivers select based on their perception of the roadway, while the design speed is a measure that engineer's use to select the roadway features for a highway. These can be vastly different from one another, which is why research needs to be completed to determine which variables affect drivers' choice of operating speed. One of the significant weaknesses of the design speed concept is that it uses the design speed of the most restrictive geometric element within the roadway section, usually the horizontal or the vertical curve of the alignment, as the design speed of the entire road. Several studies indicate that horizontal curvature is highly related to crashes. (FHWA, 2015). Different roadway sections convey different vehicle speed. Vehicles can travel at higher speed in the straight stretches of a roadway. In conventional geometric design, this fact is ignored and safe speed at curve sections is considered for the roadway design. For example, a straight section allows drivers to travel faster and curve section restricts driver to slower speed. When successive geometric elements are not designed in coordination, inconsistency in speed may cause those elements unsafe (Gong and Stamatiadis, 2008). Generally, speed inconsistency increases driver's workload, which violates driver's expectancy achieved from their driving experience. If the total driver workload exceeds their capacity, the driving performance may deteriorate. Finally, excessive deterioration of driver performance can lead to a crash. This research study presents an Empirical research consistency model to estimate the 85th percentile operating speed for the horizontal alignment at two-lane rural highway. Scope of the study work is focused on the rural highways of Nepal where traditionally we have been following the Nepal Standard Road (2070) Guidelines for the design of the geometric parameters of the highway which has already given the speed limit regarding the geometric features. Those design speed is really impracticable and impossible to gain on the real road vehicle moving practice. So, it very necessary to update the design data and replace all the design speeds with the operating speed which will be the best result oriented for the free-flowing vehicles in highway in Nepal. It is important and useful to conduct this research study for the entire highway network. Due to limitation of data availability the study is focused on the road section of Naubise to Nagdhunga road. This road section is the major route from the view point of trade, commerce and mobility and also has difficult terrain as elevation changes from 952m to 524m within the stretch of 12km with hundreds of horizontal and vertical curves.

2. Review of the literature

There have been done numerous studies in south Asia that presented model to predict 85th percentile free flow speed in terms of the road geometry. Data were collected from a set of curves. The independent variable considering operating speed model includes degree of horizontal curve, lane width, length of horizontal curve, shoulder width, super elevation, available sight distance, vertical grade etc. For each curve, speed was measured at three points including point of curvature, midpoint of the curve and the point of tangency. From the studies, it was noted that for the same horizontal curve, there were significant difference between operating speed at point of curvature, point of tangency and midpoint of the curve. This difference increased with the increase of radius of curvature. According to them, curve radius was the only statistically significant independent variable in predicting 85th percentile operating

Table 1
Previously Developed Speed Prediction Models

Speed Prediction Model		Location	R^2
Lamm et al. (1990)		Two-lane rural highway curves, grades	
V85	$= 93.85 - 1.82DC$	< 5%	0.79
McLean (1979)		Two-lane rural highway curves	
V85	$= 53.8 + 0.464VF - 3.26(1/R)*10^3 + 8.5(1/R)^2 *10^4$		0.92
Passetti et al. (1999)		Two-lane rural highway curves	
V85	$= 103.9 - 3030.5(1/R)$		0.68
Kanellaidis et al. (1990)		Two-lane rural highway curves	
V85	$= 129.88 - 623.1/(1/R)^{0.5}$		0.78
Glennon et al (1983)		High-speed rural alignments,	
V85	$= 150.08 - 4.14DC$	grades < 5%	0.84
Ottesen et. al (2000)		Two-lane rural highway curves,	
V85	$= 102.44 - 1.57DC + 0.012L - 0.01DC*L$	grades < 5%,	0.81
V85	$= 41.62 - 1.29DC + 0.0049L - 0.12DC*L + 0.95Va$	3 < degree of curvature < 12	0.91
McFadden et al. (1997)		Two-lane rural highway curves	
V85	$= 104.61 - 1.90D$		0.74
V85	$= 103.13 - 1.58D + 0.0037L - 0.09$		0.76
V85	$= 54.59 - 1.50D + 0.0006L - 0.12 + 0.81V_a$		0.81
Andjus (1998)		Two-lane rural road curves,	
V85	$= 16.92 \ln R - 14.49$	grades < 4%	0.98
Islam et al. (1997)		Two-lane rural highways	
V85 (1)	$= 95.41 - 1.48*DC - 0.012*DC^2$	(1) beginning of curve	0.99
V85 (2)	$= 103.03 - 2.41*DC - 0.029*DC^2$	(2) middle of curve	0.98
V85 (3)	$= 96.11 - 1.07*DC$	(3) end of the curve	0.90
Schurr et al. (2002)			
V85	$= 103.3 - 0.1253DA + 0.0238L - 1.038G_1$	Two-lane rural highways	0.46
Andueza (2000)		Two-lane rural highways	
V85 (1)	$= 98.25 - 2795/R2 - 894/R1 + 7.486D + 9308L1$	(1) horizontal curves	0.84
V85 (2)	$= 100.69 - 3032/R1 + 27819L1$	(2) tangents	0.79
Jessen et al. (2001)		Two-lane rural highways	
$V_{mean}^{(1)} = 67.6 + 0.39V_p - 0.714G_1 - 0.00171\ T_{ADT}$		(1) crest vertical curve with limited stopping sight distance	
$^{V}85$	$^{(1)} = 86.8 + 0.297\ V_p - 0.614G_1 - 0.00239\ T_{ADT}$		0.57
V95	$^{(1)} = 99.4 + 0.225\ V_p - 0.639G_1 - 0.0024T_{ADT}$		
$V_{mean}^{(2)} = 55.0 + 0.5V_p - 0.00148\ T_{ADT}$		(2) approach tangent	0.54
$^{V}85$	$^{(2)} = 72.1 + 0.432V_p - 0.00212T_{ADT}$		0.57
$^{V}95$	$^{(2)} = 82.7 + 0.379V_p - 0.002T_{ADT}$		0.44
Fitzpatrick et al. (2000)		Two-lane rural highway	
V85 (1)	$= 102.10 - 3077.13/R$	(1) horiz. curve, –9% < grade < –4%	0.42
V85 (2)	$= 105.98 - 3709.90/R$	(2) horiz. curve, –4% < grade < 0	0.40
V85 (3)	$= 104.82 - 3574.51/R$	(3) horiz. curve, 0 < grade < 4%	0.58
V85 (4)	$= 96.61 - 2752.19/R$	(4) horiz. curve, 4% < grade < 9%	0.76
V85 (5)	$= 105.32 - 3438.19/R$	(5) horiz. curve with sag vertical curve	0.76
V85 (6)	$= 103.24 - 3576.51/R$	(6) horiz. curve combined with limited sight distance crest vertical curve	0.53
V85 (7)	= assumed desired speed	(7) sag vertical curve on horizontal tangent	0.92
V85 (8)	= assumed desired speed	(8) vertical crest curve with unlimited sight distance on horizontal tangent	0.74

speed for all alignment combination. Operating speed on horizontal curve drop sharply when the radius of curve is less than 100 m. In general, design speed is higher than operating speed on high speed roadways, while lower than operating speed on low speed roadways. It was found that 85th percentile operating speed increases with increase of speed limit. Manually operated spot speed method was used to collect the speed data. They proposed a model for operating speed prediction. Model was developed using statistical methodologies. It was concluded that the selection of operating speed prediction model had a significant effect on evaluating the design consistency.

A. Operating Speed Prediction Models

Studies on operating speed prediction models started in 1950's (Taragin and Leisch, 1954, Gong and Stamatiadis, 2008). Since then both linear and nonlinear regression models are developed to predict operating speed of cars and trucks over various locations on the curved two-lane roads. A summary for the predictor variables used in the previously developed models is presented in Table 1.

In country like Nepal, there is no in-depth investigation that has been reported on the 85th percentile operating speed model for horizontal alignment that is reflective on Nepalese rural highway condition. Up to this date, Nepal Road Standard 'A Guide on Geometric Design of Roads' (2070) only set consideration on the individual elements for which the geometric parameters should be selected or determined to satisfy the minimum requirement and no design consistency models that can be used to evaluate the geometric design on horizontal alignment at two lane rural highway.

Overall geometric design of a road is the function of design speed. Design speed is decided based on the importance of the road (road class) and the type of terrain. The design speed to be adopted for various classes of roads is given in table 2 which seem rarely to be practical in practice.

Table 2
Design speed of vehicle as per NRS 2070

Road Class	Plain	Rolling	Mountainous	Steep
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

Category	Plain	Rolling	Mountainous	Steep
National Highway	I	II	II	III
Feeder Roads	II	III	II	IV

B. Multi-linear regression (MLR) model

Multi-linear regression is a statistical technique to model the linear relationship between the independent and dependent variables which are explanatory and response variables respectively. As per MLR model, y-variable is related to p-1 variables as

$y_i = \beta_0+\beta_1 x_{i,1}+\beta_2 x_{i,2}+\ldots+\beta_{p-1} x_{i,p-1}+\epsilon_i$. In this equation, the following assumption is made • ϵ_i have a normal distribution with mean 0 and constant variance σ^2. Here, i subscribe refers to the population's individual ith. The subscript following i simply denotes what variable it is in the notation for the x-variables. In multi linear regression, the word "linear" refers to the fact that the model is linear in parameters, $\beta_0, \beta_1,\ldots,\beta_{p-1}$. This simply means that each parameter β_i multiplies an x-variable x_i while the function of regression is a sum. Each x - variable can be a predictor variable or a predictor variable transformation (such as square, cube or of higher degree of predictor variable). Thus, in multiple linear regression, the non-linear relationships between the response and predictor variables can also be represented by allowing non-linear transformation of predictor variables. The β coefficient estimates are the values that minimize the sample sum of squared errors. The letter b is used to represent a β-coefficient sample estimate. Therefore, b_0 is the β_0 sample estimate, b_1 is the β_1 sample estimate, and so on.

- $MSE=SSE/(n-p)$ estimates variance (σ^2) of the errors.
- $S=\sqrt{MSE}$ estimates σ and is known as residual standard error.

where, n = sample size, p = number of β coefficients in the model, MSE= mean squared errors and SSE= sum of squared errors. Each β coefficient represents the change in the mean response, E(y), per unit increase of the associated predictor variable when all other predictors are kept constant. For example, β_1 is the change in the mean response, E(y), per unit increase in x_1 if $x_2, x_3,\ldots,x_{p-1}$ is kept constant. The intercept term, β_0, is the mean response, E(y), if all x_1, x_2, x_3 predictors when all the predictors $x_1, x_2, x_3\ldots x_{p-1}$, are all zero

C. Model validation

Model validation is done by testing of a model with the sets of data that represents actual field conditions. In order to validate the model, independent sets of field data (that are not used in model development) are to be used. The uncertainty in prediction of the actual model leads to the prime importance of this step.

D. R Squared and Significance F

R Squared delineates to what degree the output variable's variance is explained by the input variables' variance with respect to the real data. For example, 0.5 R Squared means 50% of the output variable's variance is explained by the input variables' variance. Significance F indicates whether the regression output could have been obtained by certain circumstances. The validity of regression output is confirmed by the small Significance F value. For example, 0.05 Significance F means there is only a 5% probability that the regression output could have occurred by chance.

E. Correlation Coefficient

The correlation coefficient (or Pearson correlation coefficient) is often used to access, measure and describe the strength along with the direction of the relationship between

Table 3
Geometrical data

Chainage	Radius	Deflection Angle	Width	LOC	Gradient	Super Elevation	Shoulder Width
0+190	34.21	67	7.40	40.00	-4.58	1.25	0.40
0+500	42.97	40	7.00	30.00	-10.70	2.88	0.30
0+920	35.81	40	7.90	25.00	-3.50	3.24	0.90
1+350	20.36	76	8.00	27.00	-2.65	4.00	1.00
1+800	100.27	20	8.40	35.00	-5.79	4.63	1.40
2+300	14.19	105	7.30	26.00	-9.89	4.15	0.30
2+567	33.48	77	7.00	45.00	-4.92	3.52	0.50
2+750	23.87	120	7.20	50.00	-3.87	2.14	0.20
3+125	33.06	78	7.40	45.00	5.91	7.56	0.40
3+500	21.49	80	7.90	30.00	7.11	3.91	0.90
3+900	62.67	32	8.20	35.00	-6.84	2.76	1.20
4+175	29.42	74	8.30	38.00	5.46	2.43	1.30
4+700	45.23	38	7.12	30.00	1.92	1.69	1.20
4+932	22.28	108	8.30	42.00	0.15	4.73	1.30
5+165	20.22	85	7.70	30.00	-2.91	3.62	0.70
5+466	22.92	80	7.90	32.00	1.98	6.19	0.90
5+638	70.52	26	9.00	32.00	5.42	2.97	2.00
5+975	31.51	60	8.70	33.00	-5.87	1.64	1.70
6+148	84.80	25	9.00	37.00	-4.59	4.62	1.70
6+364	65.12	41	8.50	46.60	5.66	2.47	1.50
6+549	33.52	67	9.20	39.20	-0.55	2.87	1.50
6+745	64.42	41	9.30	46.10	-2.55	2.14	1.20
6+930	88.27	32	8.40	49.30	2.68	3.63	0.90
7+255	40.45	67	8.00	47.30	0.09	3.39	1.20
7+604	61.24	45	8.50	48.10	4.58	1.78	1.00
7+800	38.82	71	8.60	48.10	-0.18	0.36	0.90
8+263	32.26	73	8.60	41.10	-4.18	1.91	1.00
8+467	81.20	29	8.10	41.10	5.59	2.50	0.90
8+636	56.61	50	7.30	49.40	6.53	2.78	1.00
8+810	47.25	77	7.20	63.50	-2.55	6.25	1.00
9+067	124.86	24	8.20	52.30	-3.16	1.55	1.10
9+290	345.21	8	9.10	48.20	6.30	2.64	1.00
9+538	190.60	15	9.00	49.90	-1.18	3.81	1.00
9+872	189.71	18	9.10	59.60	-1.42	4.34	1.00
10+142	244.33	14	8.50	59.70	3.50	1.90	1.70
10+451	189.08	24	7.00	79.20	-0.87	3.93	1.50
10+850	30.36	87	7.00	46.10	-4.47	3.43	1.10

two numerical variables. Professionals show proclivity to consider one or more variables from the sets of data and their relationships in traffic engineering problems and 1.00 and +1.00 are two extreme end values of the correlation coefficient. The positive coefficient depicts the increasing relationship between two variables and vice versa by negative coefficient. A correlation coefficient of 0 indicates that the movements of the variables are totally random i.e. an increase in first variable doesn't show any expected directional movement of other variable research works. The relationship amongst two variables can be statistically measured by the correlation coefficient.

3. Methodology

A. Site Selection

Nepal has different categories of highway road classes. The site selected for the case study areas is located in Dhading district, two-lane rural highways, which have higher traffic jam factor occurrence. The study area has criteria such as the classification of road is National Highway, guidelines that provide high geometric standards and usually serve long to intermediate trip lengths with high to medium travelling speeds. The speed data has been collected for passenger vehicles in traffic stream under free flow conditions. The horizontal site was selected with the following criteria;

- (i) no intersection being along this site;
- (ii) no physical features that make an obstruction of operating speed such as speed reducer, or traffic light system along the site;
- (iii) The road must good dry condition because in wet or rainy condition that make the operating speed become slow.

Fig. 1. Nagdhunga-Naubise Road Section Map

Lane discipline is assured by considering the following the two conditions:

Condition A: Maintaining at least 5sec headway between the subject vehicle and its lead vehicle.

Condition B: No parallel movements in adjacent lane or space.

B. Data Collection and Reduction

Data were collected randomly from 47 locations of two-lane rural highways as stated below. The range of radius varied from 15 m to 400 m. The selected two-lane rural highway sites had good pavement conditions with high traffic volume. The sites were not close to towns or developed areas where roadside conditions might have affected the operating speeds of vehicles travelling on the curves.

The survey was carried out throughout the roadway section. The linear distance was measured using measuring tape. The bearings were plotted in AutoCAD 2007 and the horizontal curves were drawn. From the circles drawn, the radius R is found out. The angle at which they meet gives the deviation angle Δ. The lengths of the circular curve, transition curves, and approach and exit straights had measured using formulae of simple circular curve.

The alignment consists of many parameters such as Radius of curvature (R), deviation angle (Δ), length of curve (LC), carriageway width (CW), super-elevation (e), roadway gradient (g) etc. The geometric features of the various curves are presented in table 2. Deviation angle is in degrees. The other parameters are in meters. The geometric information has been obtained from field visit, survey works and other data by plotting on AutoCAD2007. For the horizontal curve, the data included has been; radius of circular curve (RC) and length of circular curve (LC). These geometrical data are shown in table 3.

C. Speed Data

The speed data were collected for passenger cars during daylight, off-peak traffic periods, and under dry-weather conditions. A sufficient number of vehicle speeds were observed so as to limit the statistical sampling error. At least

Table 4
Speed data

Chainage(km)	85th Percentile Operating Speed (kmph)			98th Percentile Operating Speed (kmph)			50th Percentile Operating Speed (kmph)		
	Beginning of Curve (Vbc)	Mid of Curve (Vmc)	End of Curve (Vec)	Beginning of Curve (Vbc)	Mid of Curve (Vmc)	End of Curve (Vec)	Beginning of Curve (Vbc)	Mid of Curve (Vmc)	End of Curve (Vec)
0+190	42	40	44	57.24	55.96	59.96	35	30	38
0+500	42	41	45	58.32	48.84	54	36	30	34
0+920	39	38	42	53.92	48.84	59.28	36.5	30	34
1+350	23	25	31	52	45	49.96	33	27	31
1+800	59	49	60	45.96	46.6	52.32	23	23	30
2+300	22	24	28	52.64	48.84	59.96	29	26	31
2+567	40	36	43	52	52.56	49.28	36	32	34
2+750	44	40	45	49.96	49.8	58.32	31	27	30
3+125	43	32	41	52	46.8	44.96	36	33	36
3+500	29	22	27	48.64	48.84	52	34	27	31
3+900	45	42	43	54.32	55.64	59.96	22	25	31
4+175	30	36	27	48	57	48.32	36	32	38
4+700	44	37	42	52	48.84	48.64	31	27	33
4+932	37	33	36	52.84	46.6	53.6	33	30	36
5+165	37	36	39	48	48.84	47.64	31	24	29
5+466	32	27	39	50.6	48.4	59.96	33	27	36
5+638	59	45	50	65.96	57	63.96	38	29	39
5+975	39	30	44	53.48	57	57.96	32	26	35
6+148	59	48	62	48	57	52.32	30	25	31
6+364	45	42	43	52	50.88	59.28	35	32	36
6+549	49	36	50	58.92	55.64	62.64	37	26	37
6+745	47	39	49	58.64	50.88	57.28	37	33	42
6+930	59	48	51	64	48.6	64.32	41	32	41
7+255	44	34	43	68.24	47.64	63.32	42	30	44
7+604	46	35	44	64.7056	57.36	64.0896	42	30	44
7+800	43	29	45	41	30	40	37	26	37
8+263	50	39	58	63	58	63.32	36	23	37
8+467	63	50	62	54.96	43.96	58.32	47	30	45
8+636	51	45	49	53.24	35.56	58.32	47	27	48
8+810	39	38	43	66.64	50.28	69	50	27	53
9+067	65	50	69	79.88	110.28	73.96	51	28	51
9+290	81	66	72	79.2	40.6	79.52	50	26	52
9+538	70	55	72	70	56.64	72	52	30	52
9+872	66	49	67	70.6	43.96	73.64	41	27	40
10+142	64	46	60	74.64	44.96	75.64	28	24	29
10+451	70	51	71	72.92	55.24	77.32	33	27	36
10+850	33	28	39	72.92	55.24	77.32	38	29	39

150 observations were recorded at each site in order to assure an adequate sample size to obtain a 95 % level of confidence under free-flow traffic conditions. The sample size requirements for 85th percentile speed was determined through application of the following equation

$$N = \frac{\sigma^2 K^2 (2 + u^2)}{2E^2}$$

Where,

N= minimum number of measured speeds;

σ = estimated sample standard deviation (± 8.5 km/h);

K = constant corresponding to the desired confidence level (1.96);

E = permitted error in the average speed estimation (± 1.6 km/h); and

u = constant corresponding to the 85th desired percentile speed (1.04). The speed data were collected using a hand-held radar meter (Speed Gun type Bushnell). Only free-flowing vehicles have been included; the study defined a free-flowing vehicle as having at least 5 s headway. Vehicles that braked, turned, or exhibited any unusual behavior had not been recorded. Data has been collection along with dry pavement conditions in daylight hours, usually between 7:00 am and 6:00pm. The major tasks of this research were the collection and reduction of field data to be used in the development of the operating speed models. These data include the operating speed data and geometrical elements data at the selected areas.

The speed of the vehicles was taken at three different sections along the horizontal curves.

(1) At the entry of curve.
(2) At the circular curve.
(3) At the exit of curve.

The geometric element data from the data collection form has been entered into the spread sheet system filling. In order to achieve the objectives, data from four curves had used for further analysis in the multiple linear regression analysis. These four different curves has been carried out for the operating speed observation with different geometric elements of horizontal curves, while the geometric design elements data such as the length of curve, radius of curve, gradient of curve and super elevation at the selected curve section has been carefully investigated. The data collected by Radar Gun has been usually taken only from passenger vehicles at the selected area in which the study that has been conducting. These data has been used to determine the speed characteristics of the vehicles travelling on the selected area. Therefore, it is necessary to obtain the 85th percentile speed. The multiple linear regression analysis has been performed.

D. Model framework

The effect of most predominant variables on the speed prediction on the horizontal curve can be modelled with multiple linear regression technique. With the help of multiple linear regression model, operating speed was estimated with the variables relating to traffic and geometric parameters (Table 1). Multiple Linear Regression Model Multi-Linear Regression model was developed using Statistical Package for the Social Sciences (SPSS) software package to ascertain the relationship between V 85th operating with the traffic and geometric parameters on Naubise –Naghdunga horizontal curve valley. The MLR model represents the number of Operating Speed which includes significant explanatory variables at 95% confidence interval. t-test was carried out and the significance of the variables was extracted from the software.

E. Model Validation

The field data of Operating Speed were fed to the developed MLR model. The predicted value of Operating Speed from the MLR model were observed to see if the predicted values matched the observed field values. For this, linear regression analysis was performed using SPSS software. The developed model was validated by using those data that were omitted (approximately 25% of the randomly selected reserve data) in the model development process, at the same sites under similar conditions. The output given by the developed model were compared to the corresponding observed field values. For those data sets, the strength of relationship was analysed by means of R Squared and Significance F values and goodness of fit was judged.

4. Data analysis and results

A. Correlation matrix

Correlation matrix among the variables was developed to ascertain the strength of correlation of one variable with another (Table 4). Only one variable from the sets of variables having strong correlation can be taken for regression analysis.

B. Multi-linear regression (MLR) Model

Based on the correlation matrix between independent and dependent variables number of model alternatives have been fitted. The coefficients of variables and the equation of each MLR model is represented below.

Model I: Considering all Variables

This is the first MLR model developed considering all variables. In this model, only one of the predictor traffic speed seems to be significant at 95% confidence interval. t-test conducted on this variable shows value of more than 1.96 and p-value is less than or equal to 0.05.

For beginning of curve

R Squared Value = 0.837 (i.e. 83.7% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.05 (i.e. there is only 0.5% possibility that the regression output was merely a chance occurrence)

Regression Equation:

V_{85}=20.359+.059R-0.225D+3.047W+.347LC-0.180SE+0.17G-3.472SW

Table 5
Variables

Variables	Significance	Beginning of Curve ($V50^{th}$)	Mid of Curve ($V50^{th}$)	End of Curve ($V50^{0}$)	Beginning of Curve ($V85^{th}$)	Mid of Curve (V85th)	End of Curve (V85th)	Beginning of Curve (V98th)	Mid of Curve (V98th)	End of Curve (V98th)
Radius	Pearson Coefficient	-0.118	-0.12	0.177	0.842	0.801	0.79	0.646	0.475	0.796
	SIG.(2-Tailed)	0.582	0.956	0.409	0	0	0	0.01	0.19	0
Length of Curve	Pearson Coefficient	0.364	0.464	-0.515	0.559	0.457	0.564	0.277	0.362	0.318
	SIG.(2-Tailed)	0.08	0.21	0.1	0.001	0.004	0	0.19	0.82	0.13
Deflection Angle	Pearson Coefficient	0.0358	-0.061	0.183	-0.8	-0.777	-0.747	-0.508	-0.342	-0.644
	SIG.(2-Tailed)	0.859	0.973	0.392	0	0	0	0.11	0.102	0.001
Gradient	Pearson Coefficient	0.398	0.98	0.381	0.236	0.152	0.468	0.64	0.85	0.217
	SIG.(2-Tailed)	0.054	0.054	0.66	0.159	0.368	0.036	0.01	0.694	0.309
Super elevation	Pearson Coefficient	0.022	0.022	0.142	-0.147	-0.136	-0.123	0	0.138	0.049
	SIG.(2-Tailed)	0.92	0.92	0.508	0.386	0.423	0.468	0.999	0.52	0.821
Shoulder Width	Pearson Coefficient	0.354	0.43	0.73	0.291	0.194	0.83	0.392	0.53	0.75
	SIG.(2-Tailed)	0.25	0.26	0.23	0.081	0.249	0.232	0.9	0.12	0.75
Carriage Width	Pearson Coefficient	0.098	0.534	0.358	0.24	0.139	0.207	0.366	0.628	0.362
	SIG.(2-Tailed)	0.675	0.007	0.085	0.152	0.41	0.219	0.079	0.001	0.82

For middle of curve

R Squared Value = 0.750(i.e. 75.0% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.05 (i.e. there is only 0.5% possibility that the regression output was merely a chance occurrence).

Regression Equation:

V85=38.379+0.048R-0.169D+0.696W+0.126LC-0.127E+0.035G-3.628SW

At End of curve

R Squared Value = 0.796 (i.e. 79.6% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.05 (i.e. there is only 0.5% possibility that the regression output was merely a chance occurrence)

Regression Equation:

V_{85}=14.322+.046R-.199D+3.419W+0.386LC-0.098E-0.530G-3.418SW

Model II: Considering Significant Variable

Only a series of combination constituting different variables are selected for the analysis of the significance of the individual variables. From the sets of combinations, it can be concluded that traffic speed is the only significant predictor of Operating Speed.

For beginning of curve

R Squared Value = 0.509 (i.e. 50.90% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.05 (i.e. there is 5% possibility that the regression output was merely a chance occurrence

Regression equation:

V_{85} (SC) = 41.984+ 0.072R – 0.219D + 0.282LC

For middle of curve

R Squared Value = 0.723 (i.e. 72.30% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.000 (i.e. there is 0% possibility that the regression output was merely a chance occurrence)

Regression Equation:

V_{85} (MC) = 42.001 + .065R - .133D

For end of curve

R Squared Value = 0.776 (i.e. 76.30% of variance of original field data is explained by the variance of field data obtained from MLR equation.)

Significance F = 0.05 (i.e. there is 5% possibility that the regression output was merely a chance occurrence)

Regression Equation:

V_{85} (EC) = 39.936+ 0.060R - 0.193D + 0.327LC - 0.509G)

C. *Validation of MLR model*

From the total 47 data sets, further 10 data sets (nearly25%) of the data sets (those data sets which were not used in developing the MLR model) were selected for validating the developed model II. Regression analysis between observed value and predicted value of Operating Speed yielded the following results.

- R Squared Value = 0.5136,.9161,.966 (i.e. 51.36. %, 0.91.61%, 0.96.66% of variance of original field data is explained by the variance of field data obtained from MLR equation at beginning, middle and end curve respectively).
- Significance F = 0.05 (i.e. there is only 5% possibility that the regression output was merely a chance occurrence) • Regression Equation: Observed Value at BC = 3.5015 + 0.8282 * Predicted Value

Observed Value at MC = 15.436 + 0.6577 * Predicted Value

Observed Value at EC= 5.8232 + 1.0583 * Predicted Value

D. *Remodeling using validation data*

First of all, only 75% of the total data were used for developing the MLR model. Then the developed model was validated by remaining 25% data. After the validation of developed model, again the final model was developed considering all data (i.e. data used in initial model development and validation for begging of curve R Squared Value = 0.80 (i.e.

80% of variance of original field data is explained by the variance of field data obtained from MLR equation.) while for middle of curve of curve R Squared Value = 0.716 (i.e. 71.6% of variance of original field data is explained by the variance of field data obtained from MLR equation.) And R Squared Value = 0.65 (i.e. 65% of variance of original field data is explained by the variance of field data obtained from MLR equation.) For end of curve of curve Significance F = 0.05 (i.e. there is 5% possibility that the regression output was merely a chance occurrence)

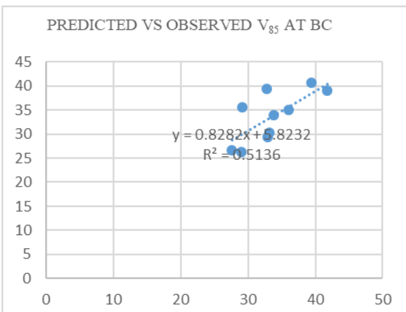
Regression Equation:

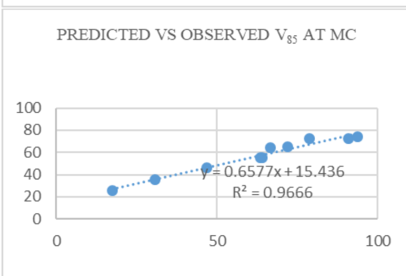
V_{85} (BC) = 43.788+0.075R-0.196D+0.230LC

V_{85} (MC) = 40.168+0.070R-0.118D

V_{85} (EC) = 40.212+ 0.054R - 0.194D + 0.320LC -5.05G

Similarly, Chi Square test have been used to validate the equations shown in table.





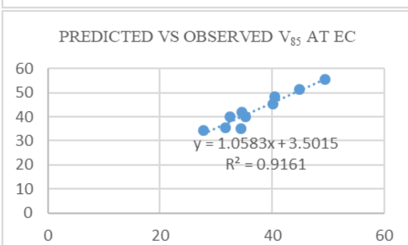


Table 6
Tests

S. No.	TESTS	SE at BC	SE2 at MC	SE at EC
1	MSE	5.67	2.86	8.59
2	MAPE	0.13	0.08	0.16
3	RMSE	3.45	3.57	10.37
4	CHI SQUARE VALUE	9.92	5.54	16.227

5. Discussions and conclusions

The following points can be drawn from the study;

1. The range of radius of curvature used in the stretches lies between 15 to 389m.
2. The radius of curvature, deviation angle and length of curve are important parameters which influence the operating speed. This indicates that drivers select their operating speed based on the geometric parameters and the curve itself mainly influences a driver's speed choice.
3. Deviation angle is the dominant factors in case of entry curve and become less significant at circular and exit curvature. The radius of curvature is more effective on the operating speed at the circular than at the other two locations.
4. There were also some insignificant trends observed. The geometric features like curve length, gradient, super elevation, carriage width are less significant and does not influence operating speed.
5. The coefficient of determination (R2) of at the final curve is higher than that at the entry and mid of the curve.

Compared to results of other studies such as Hassan (2005), Kanellaidis et. al. (1990) the relationship between the operating speed at the entry of a horizontal curve and the radius of the curve and other alignment parameters is relatively weak, having a low coefficient of determination R2. This may be due to the variations between the geometrics of highway in hilly terrain. From the model developed, the operating speeds can be predicted. The difference in the operating speed between the successive elements of the highway is use in evaluating the design consistency. A large difference in the 85th operating speeds between the successive elements of the highway reflects the lack of design consistency in the highway section. Besides the ability of evaluating the design consistency of the highway, the outcome of this study can be used to implement and enhancement into the current guideline of geometric design of highway. It could play an important role in designing or redesigning of the horizontal alignment for two-lane highway in Naubise–Nagdhunga Road. Because of the requirement of varying independent parameters, the different site location has been selected for the validation of the equation and due to the time limitation, the validation of the model cannot be completed which will be shown in final report. Within the limitations of the studied sites, the conclusions drawn from the analysis of the data are presented below.

1. From among 6 candidate independent variables presented, the 4 independent variables that were selected for entry into the speed prediction equation for 85th percentile curve speed through application of stepwise multiple regression analysis techniques to data from 36 observed sites were: 85th percentile approach speed; radius; deflection angle; and super elevation.
2. The independent variables that entered into all the 85th percentile curve speed prediction equations after stratifying these data into four different ranges of

grade were 85th percentile approach speed and radius.

3. When the three individual equations developed for different ranges of grade were applied to the data from 10 validation sites, the mean absolute percent error (MAPE) in predicting 85th percentile curve speed ranged from 7 to 9 percent. Overall, the performance of the equations showed a MAPE of 8 percent.
4. By using the Chi-square test, it was determined that there was no statistically significant difference between the observed and the predicted 85th percentile curve speed.

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