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A Speed Prediction Model on Horizontal Curves of Two-Lane National Highway: A case study of Nagdhunga-Naubise Road

by

Rajesh Dhakal

A THESIS

SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN SCIENCE INTRANSPORTATION ENGINEERING

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APPROVAL LETTER

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "A Speed Prediction Model on Horizontal Curves of Two-Lane National Highway: A case study of Nagdhunga-Naubise Road Section", Submitted by Rajesh Dhakal (072/MST/262) in partial fulfilment of the requirements for the degree of Master of Science in Transportation Engineering, Nepal is a record of works carried out by him under my supervision and guidance.

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ABSTRACT

Speed prediction models has been used in many countries as a useful alternative in road design concept. Each model is different in terms of methodology, data accuracy, variability in highway geometry and predictor variables used to predict the operating speed.

This research focuses on developing a relationship between vehicles operating speed as dependent variables and road geometric elements such as radius, deflection angle, and length of curves, carriage width, gradient, shoulder width and super elevation as predictor variables in Statistical Software (SPSS V20). The speed of more than 3000 free-flowing vehicles were measured along 37 horizontal curves. Three models of predicted 85^{th} percentile curve speed with the effects of geometric elements were developed using multiple regression method. Radius of curve was found to be the most significant predictor.

The proposed model was validated with the speed and road geometrical data of 10 other curves. The R^2 values for the final predicted models at the start, mid and end of curves were obtained as 0.703, 0.643 and 0.626 respectively. Similarly, the RMSE values for start, mid and end of curves were obtained as 5.15km/hr., 2.97km/hr. and 8.48km/hr respectively whereas MAPE values for the same were obtained as 0.12, 0.09 and 0.15 respectively.

Keywords: Speed prediction model, Operating Speed, Horizontal curve, Radius, Multiple Linear Regression

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………………………

Rajesh Dhakal

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ABBREVIATIONS

AADT-Average Annual Daily Traffic

SPM-Speed Prediction Model

DoR-Department of Road

MLR-Multiple Linear Regression

GNP-Gross Net Production

GPS-Global Positioning System

HMIS-Highway Management Information System

OECD- Organization for Economic Co-operation and Development

RTA-Road Traffic Accident

SPSS- Statistical Program for Social Sciences

USA-United States of America

WHO-World Health Organization

IDA-International Development Association

RMSE-Root Mean Square Error

MAPE-Mean Absolute Percentage Error

OLS-Ordinary Linear Regression

CHAPTER ONE: INTRODUCTION

1.1 Background

The goal of transportation is generally stated as the safe and efficient movement of people and goods. In general terms, good geometric design means providing an adequate level of mobility and appropriate land use access for the proper functioning of the roadway. This must be done while maintaining a high degree of safety for all roadway users. One of the main reasons for occurrence of crash incidents is the lack of geometric design consistency, defined as ‘‘the degree to which highway systems are designed to avoid critical driving maneuver and ensure safe traffic operation’’ (Al-Masaeid et al. 1994; Hassan et al. 2001). Even though there have been multiple efforts by the government to reduce road crashes ranging from organizing public awareness campaigns to introducing various safety interventions, the number of road crashes in Nepal is on an ever-increasing trend. There are several factors that lead to occurrence of serious crashes, including human behavior, vehicle condition, weather condition, road surface and road alignments (vertical and horizontal curves) etc. (WHO, 2018). Majority of road crashes in Nepal occur in horizontal curves on the national highways.

There have been number of studies conducted in the past in finding out the significant variables affecting crash frequency. According to Zegeer et. al (1991), 500-ft radius curve was found to be 200% more likely to produce a crash than an equivalent tangent section, and a 1,000-ft radius curve is 50% more likely to produce a crash than an equivalent tangent section.

As speed and radius of curve play the most important roles in reducing road crashes, there is a need to develop speed prediction models and employ them instead of the design models currently in use to clearly understand 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 engineers use to select the roadway features for a highway. As these values can be vastly different from one another, research needs to be conducted 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 (FHWA, 2015). Hence, the possibility of choosing the lesser design speed for highway design may lead to lesser radius, sight distance, tangents etc. which make the horizontal curve zone narrower increasing the safety hazard and congestion. Thus, real-scenario predicted speeds obtained from speed prediction modelling can be an effective replacement to design speeds currently in use.

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 make 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. (Cafiso and Cava, 2009)

This research study presents an empirical research consistency model to estimate the 85^{th} percentile operating speed for the horizontal alignment at two-lane rural highway.

1.2 Problem Statement

Nepal Standard Road (DoR, 2013) has been followed for the design of geometric features of highway which has already given the speed limit regarding the road classes and land terrain basis. Design speed is also known as the maximum safe speed under comfort conditions. But it is not necessary that the drivers always follow this design speed concept rather it basically depends on their driving experiences and the existing geometric parameters which directly affects the approaching speed. Those design speed standards given by (DoR, 2013) is compulsorily to be followed on the highway road design which is really impracticable and impossible to gain on the real road free vehicle flow scenario. As per the design standard given by the NRS speed value hasn't been obtained during the real field condition and various other research done on foreign countries shows that the main drawbacks are of design speed concept module. So, it very necessary to update all those design data and replace those design speeds with the operating speed at the horizontal curves which will be the best result oriented for the free-flowing vehicles on highways of Nepal.

In this regards, it would be very effective if specific equations for the 85 percentile operating speed on a horizontal alignment at the entry, mid and at the end of curve using geometric features of the curves like radius, deviation angle, gradient, super elevation and carriage width which directly or indirectly effects on drivers perspective speed. Hence, by applying the technique of multiple linear regression analysis, a model shall be developed which can predict the best operating speed of free-flowing vehicles for horizontal curve in the Nagdhunga-Naubise section of the road.

1.3 Research objective

The main objective of this research study is to regenerate the alternatives of the design speed method for horizontal curves in national highways.

The specific objectives of this research study are:

i. To develop the model relating 85th percentile operating speed of vehicles at start, mid and end of curve with independent significant variables using multiple linear regression on two lane highways
ii. Compare the existing design speeds with the predicted operating speed model

1.4 Scope of the study

Most of horizontal curves on the national highway which have been designed as per DoR standard design guidelines shows some lagging in free-flow conditions of vehicles. The respective parameters obtained after the design such as radius, sight distance, tangent length will not be sufficient to mitigate the vehicles turning effects on the curves which only depends on drivers perspective which may be leading causes for the congestion of vehicles and crashes too However, due to time , budget constraint, and data availability the study is focused on the road section of Naubise to Nagdhunga road lies on Tribhuvan Rajpath (TRP) (NH04) which is the major route connecting the major parts of country to its capital city which had maximum number of curves in short range. Real-time spot speeds data have been used for the study which has some limitations and the assumptions.

1.5 Limitations of study

a) All the free-flowing vehicles have been included, except ambulance, fire brigade truck, tractor, Lorries, Motorbikes.
b) The study defined a free-flowing vehicle as having at least a 5 s headway
c) Vehicles that braked, turned, or exhibited by any unusual problem ultimately reduces the speed of the vehicles hence such behaviour was not considered.

d) Data has been collection along with dry pavement conditions in daylight hours, usually between 7:00 am and 6:00pm.

1.6 Organization of study

The thesis is divided into six chapters. Chapter one provides the background of the thesis, statement of the problem, purpose and objectives, scope of the study, limitations and assumptions made. Chapter two provides a review of the relevant literatures related to the road safety situation of Nepal, different speed prediction models. Chapter three contains the methodological framework of the study from site selection and data collections. Chapter four reports the analysis and interpretation of the speed predicted models along with all the relevant statistical and graphical information and application of the developed model for the identification of maximum traffic congestion prone zone. Chapter five contains the Result and Discussion while chapter six contains Research Conclusion & Recommendation from this research work for future research.

CHAPTER TWO: LITERATURE REVIEW

2.1 Terminology

Based on the American Association of State Highway and Transportation Officials, entitled 'Policy on the Geometric Design of Highways and Streets', the term 'design speed' is defined as the speed used to determine the various geometric design features of the roadway (AASTHO, 2004). The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway. The 'operating speed' is the speed at which drivers are observed operating their vehicles during free-flow conditions. The 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature. Fitzpatrick et al. (2000) found that the speed at or below which 85% of the drivers are operating their vehicles. But Poe et al. (1996) indicated that it's the speed selected by the highway users when not restricted by the other users (i.e. under free-flow conditions). 85th percentile operating speed is the most frequently used descriptive statistic for the operating speed associated with a particular location or geometric feature (AASTHO, 2004). Road Engineering Association Malaysia, (REAM, 2002) suggested that speed must be selected to establish the specific minimum geometric design elements for a particular section of the highway based on local conditions. Other features such as width of pavement and shoulders, horizontal and vertical alignment etc. are generally related to the design speed.

Abbas et al. (2011) presented an empirical research and empirical model to predict 85 percentile operating speed model for horizontal curves. The speed data measure is based on spot speed data at a specific point. Multiple linear regression equations have been developed to predict the V_{85} of the vehicle on horizontal curves in two lane rural highways. The geometric parameters such as radius of curvature and speed at the approach straight line are used to recognize the effect of V_{85} operating speed model at mid-curve.

Studies conducted on South Asia as published in Transportation Research Circular, 2010 presented different models to predict 85th percentile free-flow speed in terms of road geometry. Most of the studies on speed behavior at horizontal curves are conducted on two-lane roadways (Fitzpatrick et al., 2000; Lamm et al., 1986; Jacob and Anjaneyulu, 2013). These roads have only one lane for each directional traffic flow and usually without any median barrier. 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 above studies, it was noted that for the same horizontal curve, there was significant difference between operating speed at point of curvature, point of tangency and midpoint of the curve. This difference increased with the increase in radius of curvature. According to above literature, curve radius was found to be the only statistically significant independent variable in predicting 85th percentile operating 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 in speed limit. It can be ascertained that the selection of operating speed prediction model had a significant

2.2 Operating Speed Prediction Models

Studies on operating speed prediction models started in 1950's (Taragin and Leisch, 1954). Since then, both linear and non-linear regression models have been developed to predict operating speeds of cars and trucks over various locations on the curved segments of two-lane roads. A summary of the predictor variables used in the previously developed models is presented in Table 2.1.

Table 2.1 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

Speed Prediction Model		**Location**	R^2
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 lnR – 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) start 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
V_{95} $^{(1)}$	= 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

Speed Prediction Model	**Location**	R^2
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
V85 (9) = 105.08 – 149.69/K	(9) vertical crest curve with limited sight distance on horizontal tangent	0.80
(Gibreel, Easa and El-Dimeery, 2001)	Two-lane rural highway	
V85 (1) $= 91.81 + 0.010R + 0.468\ Lv - 0.006G_1^3 - 0.878\ln(A) - 0.826\ln(L_0)$	(1) Point 1 was set out at about 60-80 m on the approach tangent before the start of the spiral curve	0.98
V85 (2) $= 47.96 + 7.217\ln(R) + 1.534(Lv) - 0.258G_1 - 0.653A - 0.008\ L_0 + 0.020\exp(E)$	(2) Point 2 was the end of spiral curve and the start of horizontal curve in the direction of travel (SC)	0.98
V85 (3) $= 76.42 + 0.023R + 2.300 * 10^{-4}\ K - 0.008\exp(A) - 1.230 * 10^{-4}\ L_0^2 + 0.062\exp(E)$	(3) Point 3 was the midpoint of horizontal curve (MC)	0.94
V85 (4) $= 82.78 + 0.011R + 2.067\ln(K) - 0.361\ G_2$	(4) Point 4 was the end of horizontal	0.95
$- 1.091 * 10^{-4}\ L_0^2 + 0.036\exp(E)$	(4) curve and the start of spiral curve in the direction of travel (CS)	0.79
V85 (5) $= 109.45 - 1.257\ G_2 - 1.586\ln(L_0)$	(5) Point 5 was set out at about 60–80 m on the departure tangent after the end of the spiral curve.	

Where;

An	algebraic difference of vertical grades (%);
ADT	average daily traffic (vehicles/day);
CCR	curvature change rate (degree/km);
DC	degree of curve (degrees);
DF	deflection angle (degrees);
DF_1; DF_2	deflection angle for curves 1 and 2 of compound curve (degree);

E; e	super elevation rate (%)
G	vertical grade (%);
G_1	gradient preceding the curve (%);
G_2	gradient succeeding the curve (%);
k, K	length of vertical curve for 1% change in grade (%/m);
L_C	length of curve (m);
L_T	length of tangent (m);
L_O	distance between horizontal and vertical point intersection (m);
L_{T1}	length of preceding tangent (m);
L_{T2}	length of succeeding tangent (m);
L_V, L_C	length of vertical curve (m);
L_W; S_W	lane and shoulder width (m);
$Max.V_{85T}$	maximum 85th percentile speed on approach tangent (km/h);
R, RC	radius of curve (m);
R_1	radius of preceding curve (m);
R_2	radius of succeeding curve (m);
85_{MSR}	maximum speed reduction from tangent to middle of curve (km/h);
V_{85}	85th percentile speed (km/h);
V_{85C}	85th percentile speed on curve (km/h);
V_{85MC}	85th percentile speed on middle curve (km/h); V_{85T} 85th percentile speed on tangent (km/h);
V_{env}	maximum speed on tangent (km/h);
V_F	desired speed (km/h);
V_T	approach tangent speed (km/h);
V_A	curve approach speed (km/h);
V_P	posted speed limit (km/h);
Pcon	pavement condition;
OV_{85}	85th percentile speed differential calculated as different between V_{85} on two elements.

In the earlier research conducted by (Memon, Khaskheli and Qureshi, 2008) in Pakistan, the V_{85} models development was based on spot-speed data using equipment radar or laser gun, video camera recording, speed trap recording, stop watch and the latest technology used by using Global Position System GPS – VBOX equipment at specific location. In terms of geometric design consistency, operating speed (V_{85}) is widely considered to be the most notable and straightforward geometric design consistency measure and the change in speed of vehicles is a visible indicator of inconsistency in geometric design (Nicholson, 1998). But in countries like Nepal, there has been no in-depth investigation on the 85th percentile operating speed model for horizontal alignment reflecting Nepalese highway condition. Nepal Road Standard 'A manual on Geometric Design of Roads' (DoR, 2013) has provided formula for various geometric parameters based on design speed. But during the real field data collection, it was observed that those speeds were varying despite having same design speed approach on respective horizontal curves. From site visualization and data plot as shown in Figure 2.1 and Figure 2.2, it can be observed that the operating speed of vehicles varies even when the highway geometry parameters are constant which contradicts with the design speed concept established in NRS.

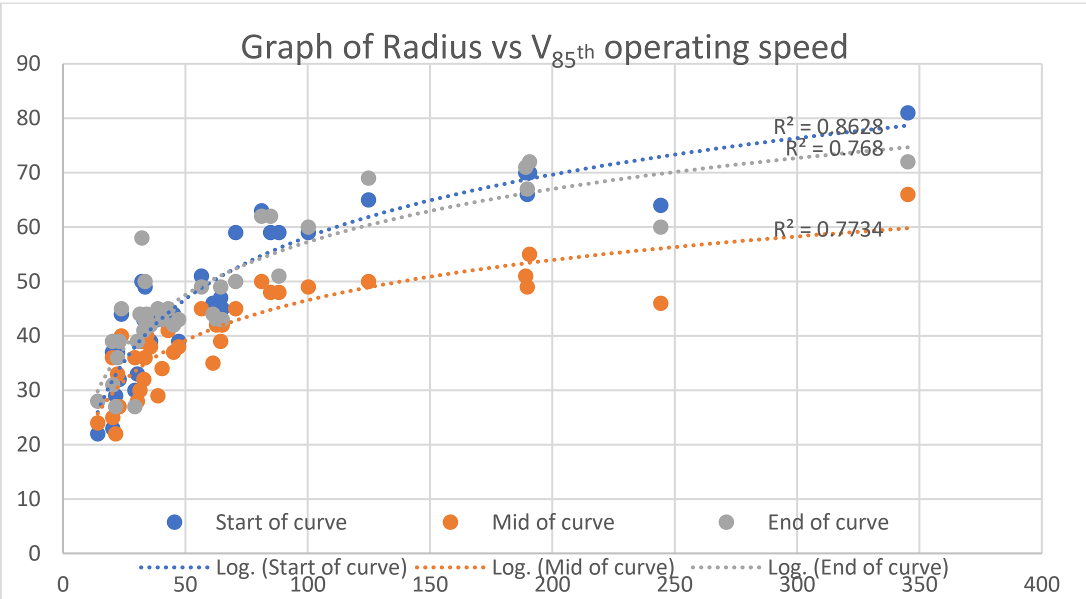

Figure 2.1 Graph of Radius of curvature versus Operating Speeds

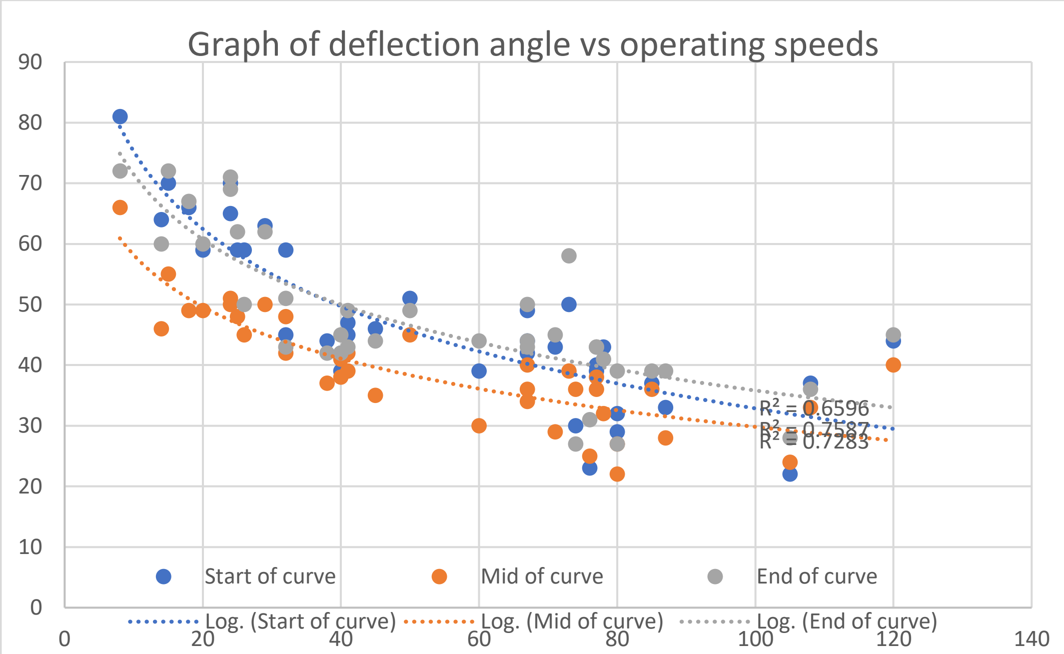

Figure 2.2 Graph of Deflection angle versus Operating Speeds

Design speed is based on the functional classification of the road and the type of terrain. Here is the design speed standards to be adopted for various classes of roads in Nepal is given in Table 2.2 which seem rarely to be practical in practice at all the horizontal curves.

Table 2.2 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
Where:	Plain and Rolling terrain		Mountainous and steep terrain	
National Highway	I, II		II, III	
Feeder Roads	II, III		II, IV	

2.3 Model Framework

A model is defined as the simplified representation of the real world which concentrated on certain elements considered important for its analysis from a particular point of view. Modeling is one important part of decision-making process. Quantitative or qualitative representation of variables in the model allows us to study the relationship that strengthens the decision-making process. The effect of most predominant variables on the dependent variables can be modelled with multiple linear regression technique.

2.3.1 Multiple Linear Regression 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 x-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 i^{th}. The subscript following i simply denotes what x-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, β_0, β_1, $\beta p-1$. This simply means that each parameter βi multiplies an x-variable xi 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, b0 is the β0 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, 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... x_{p-1}, are all zero.

2.3.2 Correlation Matrix

The correlation coefficient is a measure of the strength of the straight-line or linear relationship between two variables, taking values ranging between +1 and -1. Values between 0 and 0.3 (or 0 and -0.3) indicate a weak positive (negative) linear relationship whereas values between 0.3 and 0.7 (-0.3 and -0.7) indicate a moderate positive (negative) linear relationship. Values between 0.7 and 1.0 (-0.7 and -1.0) indicate a strong positive (negative) linear relationship (Ratner, 2008).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

Methodology section of this report has been described under the three objectives. The first is to describe the data collected and used in the development of the speed prediction models reported in this thesis. The second is to provide the details of the model development process which is also given in the fifth section of the chapter and includes information on model form and regression techniques used, method of determining appropriate error structure, methods of assessing model goodness of fit, procedure of model building and final objective of this chapter is to provide the details of the model validation and application of the model on driver's friendly operating speed in respective highway network. The general framework of methodology for this research work is illustrated in Figure 3.1.

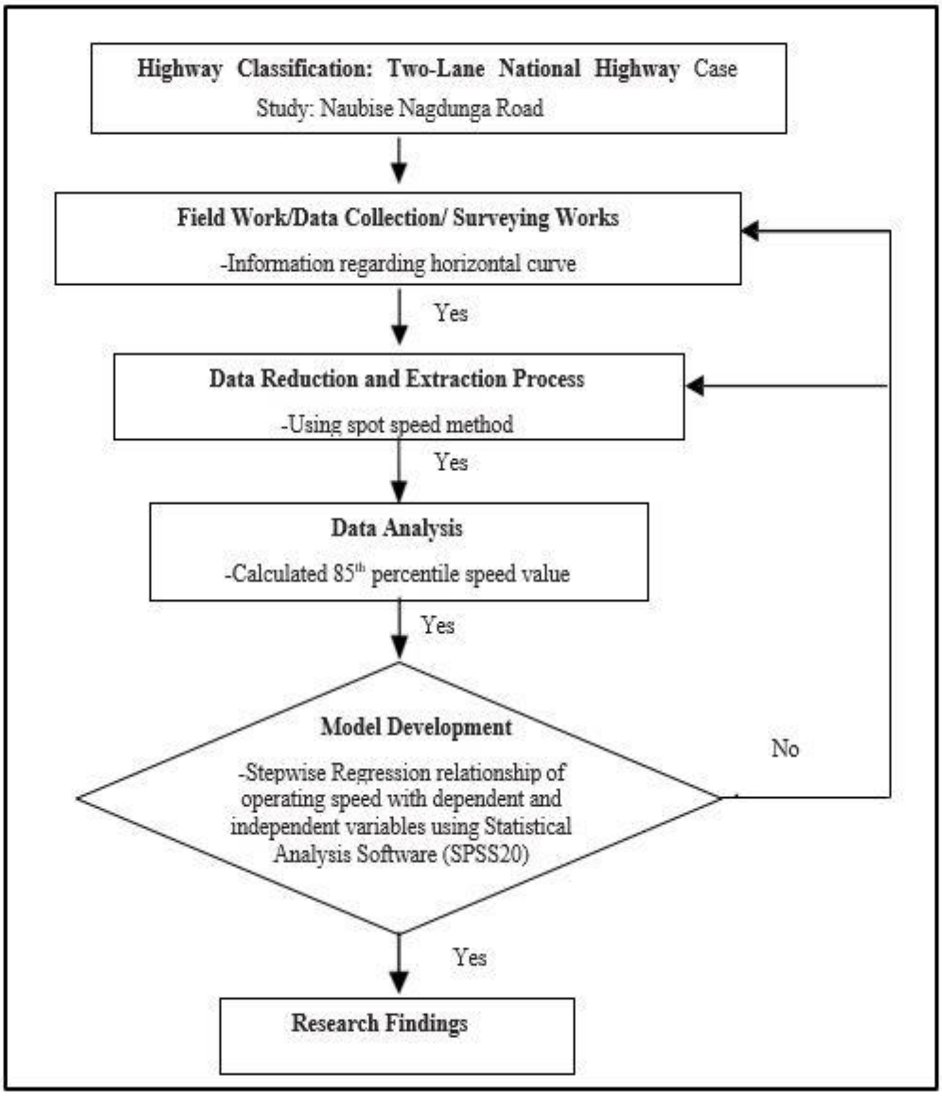

Figure 3.1 Methodology Framework

3.2 Site selection

The site selected for my research is the Nagdhunga-Naubise Section of Tribhuvan Highway as shown in Figure 3.2. The proposed road alignment lies in the Middle Mountain (Lesser Himalaya). The elevation ranges from 1,500 m (Nagdhunga) to 265 m (Naubise) from above mean sea level (msl) with a higher traffic congestion occurrence. This highway is a two-lane road with high grade and narrow intersections, sealed with Double Bituminous Surface Treatment (DBST) in almost all areas except, where regular maintenance is done. The speed data has been collected for passenger vehicles in traffic stream under free-flow conditions. The horizontal curves were selected at 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.

Figure 3.2 Nagdhunga- Naubise Road Section Map

3.3 Data Description

This section of project road was originally constructed in 1956 AD with the assistance of Government of India and later this section was rehabilitated by DoR in 1997 AD under RMRP project financed by the IDA and after that continuous improvement works such as curve widening, pavement strengthening and slope stabilization etc. are being carried out in each fiscal year. Examining the existing geometric features, the present road nearly meets the design standards of class IV road as defined in Nepal Road Standards, 2070 (Table 3.1) and design speed can be confirmed nearly as 30km/hr.

Table 3.1 Comparison of Design Parameter between Standards of DoR and Kathmandu Naubise Road (Source: EIA Report on Kathmandu-Mugling-Pokhara Upgradation Project)

Sn.	Design parameters	DOR standards class IV				Existing road			
		P	R	M	S	P	R	M	S
1	Carriageway Width m	7	7	7	7			6-7	6-7
2	Design Speed, Km/hr	60	40	30	20			30	10
3	Radius of Horizontal Curve, m	110	40	20	10			12	12
4	Max Vertical Gradient, %	7	7	7	7			8	8
5	Shoulder Width, m	1.5	1.5	1.5	1.5			0.5	0.5

Speed limits post aren't applied on most of the section, except some warning signs near urban and town areas and a few sharp bends. There are many areas to be treated for high grades, sharp bends and visibility for all road users. Crashes due to sharp bending and narrow width are high.

The speed data of passenger vehicles at SC (start of curve), MC (center of the curve) and EC (end of curve) of each site are gathered using Bushel Radar Gun. Only free-flowing vehicles are considered for speed data collection. The free-flow condition for mixed flow traffic with weak lane discipline is assured by considering the following the two conditions:

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

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

The next step in data collection involved collection of road geometry features such as radius of the curve, length of curve, gradient of the site, carriageway width, shoulder width, deflection angle and super elevation rate.

In this process, the suitability of the existing speed prediction models of two-lane roadways has been studied. For the validation, approximately 25% of the remaining data-set was selected. The output given by the developed model were compared to the corresponding observed field values. For validation, R-Squared and Significance p values were observed and goodness of fit was judged. Among 47 curves the obtained data has been divided into 37 curves for prediction and 10 curves for validation of the model.

Figure 3.3 shows the direction of vehicle flow on two lane highway on horizontal curve. The three points start, mid and end of curve on the curve is seen in three different points of same curve.

No. of curve	37
No. of hours recoded per day	12
Radius of horizontal curve, *RC* (m)	15-400
Carriage width, *Cwt.* (m)	7m -9m
Vehicles Nos.	3000

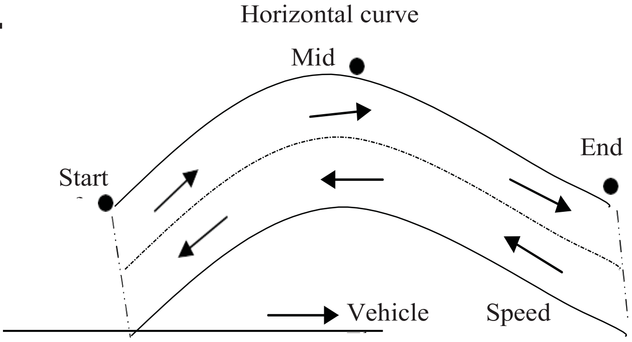

Figure 3.3 Typical Sketch of Horizontal Curve

3.4 Data collection

3.4.1 Geometrical Data

The selected site had good pavement conditions with high traffic volume. The segments considered for analysis were not close to towns or developed areas where roadside conditions might affect the operating speeds of vehicles.

The survey was carried out from Chainage 0+190 to 10+850 where the start chainage is Nagdhunga Checkpost. The length of curves 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 curves were measured using formulae of simple circular curve.

The alignment consists of many parameters such as Radius of curvature (R), deflection 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 3.2. Deviation angle is in degrees. Other parameters are in meters. The geometric data collection was done as shown in Figure 3.4.

Table 3.2 Geometric Details of Curves

Curve No.	**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

Curve No.	Radius	Deflection Angle	Width	LOC	Gradient	Super Elevation	Shoulder Width
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

Figure 3.4 Geometric Data Collection

3.4.2 Speed Data Collection

1. Speed Data

The speed data were collected for vehicles 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 83 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, (assumptions on bracket)

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 85 desired percentile speed (1.04).

The speed data was collected using a hand-held radar meter (Speed Gun type Bushnell). Values obtained from Table 3.3 and Table 3.4 were inserted in the above equation to calculate the minimum number of measured speeds.

Table 3.3 Constant corresponding to level of confidence and the percentile speed

Constant corresponding to level of confidence		Constant corresponding to percentile speed	
Constant, K	Confidence Level (%)	Constant U	Percentile Speed
1.00	68.30	0.00	50th
1.50	86.60	1.04	15th or 85
1.64	90.00	1.48	7th or 93rd
1.96	95.00	1.64	5th or 95th
2.00	95.50		
2.50	98.80		
2.58	99.00		
3.00	99.70		

Source: Box and Oppenlander 1976

Table 3.4 Standard deviation of spot speed for sample size determination

Standard Deviations of spot speeds for sample size determination			
Traffic Areas	Highway Type	Average Standard Deviation	
		mph	kph
Rural	Two-Lane	5.3	8.5
	Four-Lane	4.2	6.8
Intermediate	Two-Lane	5.3	8.5
	Four-Lane	5.3	8.5
Urban	Two-Lane	4.8	7.7
	Four-Lane	4.9	7.9

Source: Box and Oppenlander 1976

As shown in Figure 3.5, the spot speed of the vehicles was observed at start, mid and end of curves using radar gun from a particular station for each horizontal curve.

Figure 3.5 Spot speed measurement using radar gun

The geometric element data from the data collection form has been entered into MS Excel. In order to achieve realistic models, data from 10 horizontal curves was used for validation of the models. Initially the operating speeds of the free-flowing vehicles were noted on the spread sheet and various percentile speed were calculated e.g. V_{85}, $V_{98}{}^{th}$ and $V_{50}{}^{th}$ Percentile speed which is illustrated on Table 3.5**.**

Table 3.5 Operating Speed Data at the start, mid and end section of curve in various percentile speed

Chainage (km)	85th percentile Operating Speed (kmph)			98th Percentile Operating Speed (kmph)			50th Percentile Operating Speed (kmph)		
	Start of Curve (V_{SC})	Mid of Curve (V_{mc})	End of Curve (V_{ec})	Start of Curve (V_{SC})	Mid of Curve (V_{mc})	End of Curve (V_{ec})	Start of Curve (V_{SC})	Mid of Curve (V_{mc})	End of Curve (V_{ec})
0+190	42	40	44	54.24	51.84	53	32	33	33
0+500	42	41	45	53.84	60.56	54	35	35	34
0+920	39	38	42	50.92	50.84	60.28	30	29	32
1+350	23	25	31	41.92	37	39.96	17	15	20
1+800	59	49	60	65.96	58.6	74.32	49	38	53
2+300	22	24	28	29.64	32.84	43.32	16	18	19
2+567	40	36	43	52	55.56	53.28	31	30	34
2+750	44	40	45	58.32	49.8	49.96	36	33	36
3+125	43	32	41	52	45.8	46.96	34	26	33
3+500	29	22	27	38.64	38.84	35.32	18	16	19
3+900	45	42	43	54.32	55.64	54.96	36	32	33
4+175	30	36	27	38	57	37.96	22	27	21
4+700	44	37	42	56	48.84	46.64	37	30	34
4+932	37	33	36	48.84	46.6	53.6	27	24	31
5+165	37	36	39	44	48.84	46.64	24	24	28
5+466	32	27	39	39.6	34.2	52.96	22	19	29
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

Chainage (km)	85th percentile Operating Speed (kmph)			98th Percentile Operating Speed (kmph)			50th Percentile Operating Speed (kmph)		
	Start of Curve (V_{SC})	**Mid of Curve (V_{mc})**	**End of Curve (V_{ec})**	**Start of Curve (V_{SC})**	**Mid of Curve (V_{mc})**	**End of Curve (V_{ec})**	**Start of Curve (V_{SC})**	**Mid of Curve (V_{mc})**	**End of Curve (V_{ec})**
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

Table 3.6 Correlation Matrix of the Independent Variables with Operating Speed

VARIABLES	**SIGNIFICANCE**	**Start of Curve (V_{50th})**	**Mid of Curve (V_{50th})**	**End of Curve (V_{50th})**	**Start of Curve (V_{85})**	**Mid of Curve (V_{85})**	**End of Curve (V_{85})**	**Start of Curve (V_{98th})**	**Mid of Curve (V_{98th})**	**End of Curve (V_{98th})**
RADIUS	PEARSON COFFICIENT	-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 COFFICIENT	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 COFFICIENT	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 COFFICIENT	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 COFFICIENT	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 COFFICIENT	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 COFFICIENT	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

Correlation of each percentile speed variable is checked with the other independent variables as illustrated on Table 3.6 . Thus, from the correlation matrix above 85th percentile traffic speed (V_{85}) was chosen as the traffic speed variable to be used for MLR modelling.

3.5 Data Analysis and Validation

To develop the 85th percentile operating speed models at start, mid and end of curve, the respective speed has been collected and recorded where the 85th percentile operating speed were calculated from cumulative frequency plot. The regression analysis was carried out using SPSS 20. Data screening have to be conducted before using the reduced data for analysis to correctly identify data errors (Norusis, 1994). The data screen includes removing the unusual observation which may be caused due to the human errors in observation (in case of spot speed data) and measurement (in case of highway geometry variables). The total numbers of samples after removing the unusual observation were 9020 spot speeds data comprising of 83 sample spot speeds in each point of curve for 37 curves. The number of observations, mean, median, maximum value, minimum value, standard deviation, skewness and statistically plot for parameter V_{85} are as shown in Table 3.7. Average or arithmetic mean is computed by dividing the sum of individual observations by the total number of observations. In the case of symmetrical distribution, mean and median are expected to be the same value. The values of Skewness and its standard errors are below the value of 1 which are considered acceptable.

Table 3.7 General Statistical data obtain from field observations

Variable	**V85MC (km/hr.)**	**V85 (km/hr.)**	**V85EC (km/hr.)**
Number of observations	37	37	37
N valid	37	37	37
Missing	0	0	0
Mean	47.2973	47.9730	39.4865
Std. Error of Mean	2.26604	2.04326	1.54833
Median	44.0000	44.0000	39.0000
Mode	59.00	43.00	36.00

Variable	V85MC (km/hr.)	V85 (km/hr.)	V85EC (km/hr.)
Std. Deviation	9.41813	9.41813	9.41813
Skewness	0.399	.449	.391
Std. Error of Skewness	0.388	.388	.388
Range	59.00	45.00	44.00

3.6 Model Development Procedure

Various plots were used to identify possible relationships between the independent variables and the 85th percentile speed. Using the available variables, possible regression models were then developed. The values for coefficient of determination R^2, and the adjusted coefficient of determination R^2_{adj} were used to select candidate variables. At the same time, multi co-linearity among the candidate variables based on the regression models was examined for reducing potential bias. The variance inflation factor was used to test multi co-linearity. The models with high R^2_{adj} (using R^2 in simple linear models) and appropriate Cp were then chosen.

Dependent and Independent Variables

The dependent variables that were selected include V_{85} operating Speed and independent variables were carriageway width, shoulder width, super elevation, radius of curvature, deflection angle, gradient and length of curve.

3.7 Model validation

After the development of the model based on MLR, the model was statistically validated based on various validation tests of variables and test of goodness of fit. Similarly, the model was validated by chi-square value comparing the observed speed data and predicted speed data on the road section of next 10 horizontal curves.

Following statistical tests were conducted for validation:

i. **R-Squared** – R-Squared or Coefficient of Determination defines to what degree the output variable's variance is explained by the input variables' variance with respect to the real data. For example, 0.7 R-Squared means 70% of the output variable's variance is explained by the input variables' variance.

ii. **RMSE** (Root Mean Square Error) – Root Mean square Error is defined as the square root of the means and measure the imperfection of the fit of estimator which formula is given as follows:

$$RMSE= \sqrt{\frac{\sum_{i=1}^{n}(Pi-Oi)^2}{n}}$$

Where P_i is the predicted speed and O_i is the observed spot speed data

iii. **MAE** (Mean Absolute Error) – MAE is the average of the sum of the absolute difference between the observed and the predicted values which formula is given is calculated as follows:

$$MAE = \frac{\sum |O-P|}{n}$$

iv. **MAPE** (Mean Absolute Percentage Error) – MAPE is the percentage of the mean absolute error compared with the observed value which formula is given as follows:

$$MAPE = \frac{\sum \frac{|O-P|}{O}}{n}$$

v. **Chi-Squared Test** – A chi-squared test or $\chi 2$ test, is the statistical hypothesis test where the sampling distribution of the test statistic is a chi-squared distribution when the null hypothesis is true. The chi-squared test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more categories. The value for $\chi 2$ is obtained as:

$$\chi^2= \sum_{i=1}^{k} \frac{(Oi-Pi)^2}{Pi}$$

Where k-1= Degrees of freedom of the χ^2 distribution

CHAPTER FOUR: DATA ANALYSIS AND INTERPRETATION

4.1 Model development

Models were developed for start, mid and end of curve using data from 37 horizontal curves. The models developed for start, mid and end of curve will be named Model I, Model II and Model III respectively.

4.1.1 Start of Curve: Model I

As shown in Table 4.1, for the case of start of curve, radius, length of curve and deflection angle were found to be significant in 95% confidence interval (sig<0.05) i.e. there is only 5% possibility that the regression output was merely a chance occurrence. The coefficients obtained are tabulated in Table 4.1.

Table 4.1 Model Summary for start of curve: Model I Step I

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	20.359	16.899		1.205	0.028
	Radius	0.059	0.026	0.307	2.248	0.032
	Deflection Angle	-0.225	0.059	-0.477	-3.809	0.001
	Width	3.047	1.936	0.159	1.574	0.126
	Length of curve	0.341	0.116	0.285	2.948	0.006
	Super elevation	-0.180	0.728	-0.019	-0.247	0.807
	Gradient	0.017	0.232	0.006	0.074	0.942
	Shoulder width	-3.472	3.279	-0.106	-1.059	0.298

Correlation matrix of the dependent variables and predictor variables was developed to check for collinearity. The variables with multicollinearity were excluded from the model development procedure despite having strong correlation with the dependent variables.

Table 4.2 Correlation matrix for Model I

Parameters		SC	Radius	Deflection_Angle	Width	Length_of_curve	super_elevation	Gradient	Shoulder_width
SC	Pearson Correlation	1							
	Sig. (2-tailed)								
Radius	Pearson Correlation	.841**	1						
	Sig. (2-tailed)	.000							
Deflection_Angle	Pearson Correlation	-.800**	-.726**	1					
	Sig. (2-tailed)	.000	.000						
Width	Pearson Correlation	.435**	.379*	-.455**	1				
	Sig. (2-tailed)	.007	.021	.005					
Length_of_curve	Pearson Correlation	.558**	.538**	-.257	-.010	1			
	Sig. (2-tailed)	.000	.001	.124	.954				
super_elevation	Pearson Correlation	-.148	-.078	.189	-.204	.016	1		
	Sig. (2-tailed)	.382	.648	.262	.225	.924			
Gradient	Pearson Correlation	.237	.246	-.184	.231	.210	.027	1	
	Sig. (2-tailed)	.158	.142	.276	.169	.213	.874		
Shoulder_width	Pearson Correlation	.336*	.274	-.471**	.565**	.136	-.123	.271	1
	Sig. (2-tailed)	.042	.101	.003	.000	.421	.466	.105	

Table 4.2 shows the value of correlation coefficient for all dependent and independent variables.

Based on the obtained values of correlation coefficients, V_{85} speed at the start of curve has strong correlation with radius and deflection angle, moderate correlation with length of curve and weak correlation with other variables. Length of curve and radius had moderate positive correlation whereas the correlation between radius and deflection angle was found to be strong positive. The choice of the variable to be included in the final model was done based on the value of correlation coefficients of the individual predictor variables with the V_{85} speed. As we can see, the value of correlation coefficient of radius of curvature with the dependant variable at 0.841 with P value of 0.000 is higher than the correlation coefficient of deflection angle with the dependant variable at -0.800 with P value of 0.000. Thus, only radius was selected for the final model.

Table 4.3 Model Summary for start of curve: Model I Step II

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	35.651	1.766		20.186	0.000
Radius (R)	0.161	0.017	0.842	9.231	0.000

Table 4.3 shows the parameter estimates for the final model for start of curve with Radius as the only predictor variable. The variable is considered as a significant predictor as it falls within the 95% confidence interval (Sig<0.05). The final model obtained is:

$$V_{85}\ (SC) = 35.651 + 0.161R$$

Table 4.4 R-Squared Values: Model I

Model	R	R-Squared	Adjusted R-Squared	Std. Error of the Estimate
1	0.842	0.709	0.701	7.539

As shown in Table 4.4, R-Squared Value was obtained as 0.709 i.e. 70.09% of variance of original field data is explained by the variance of field data obtained.

4.1.2 Mid of Curve: Model II

For the case of mid of curve, radius and deflection angle were found to be significant at 95% confidence interval. The coefficients obtained are tabulated in Table 4.5.

Table 4.5 Model Summary for mid of curve: Model II Step I

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	38.379	14.289		2.686	0.012
Radius	0.048	0.022	0.368	2.179	0.038
Deflection Angle	-0.169	0.050	-0.524	-3.383	0.002
Width	0.696	1.637	0.053	0.425	0.674
Length of curve	0.126	0.098	0.154	1.287	0.208
Super elevation	-0.127	0.616	-0.020	-0.206	0.839
Gradient	-0.068	0.196	-0.035	-0.349	0.729
Shoulder width	-3.628	2.772	-0.162	-1.309	0.201

Based on the Correlation Matrix obtained for Model II in Table 4.6, only radius was selected for the final model as the value of pearson correlation of V_{85} at mid-curve with radius is higher than that with deflection angle at same level of significance of 0.000.

Table 4.6 Correlation matrix for Model II

Parameters		MC	Radius	Deflection_ Angle	Width	Length_of_ curve	super_ele vation	Gradient	Shoulder _width
MC	Pearson Correlation	1							
	Sig. (2-tailed)								
Radius	Pearson Correlation	.801**	1						
	Sig. (2-tailed)	.000							
Deflection_Angle	Pearson Correlation	-.776**	-.726**	1					
	Sig. (2-tailed)	.000	.000						
Width	Pearson Correlation	.334*	.379*	-.455**	1				
	Sig. (2-tailed)	.043	.021	.005					
Length_of_curve	Pearson Correlation	.457**	.538**	-.257	-.010	1			
	Sig. (2-tailed)	.004	.001	.124	.954				
super_elevation	Pearson Correlation	-.137	-.078	.189	-.204	.016	1		
	Sig. (2-tailed)	.419	.648	.262	.225	.924			
Gradient	Pearson Correlation	.153	.246	-.184	.231	.210	.027	1	
	Sig. (2-tailed)	.367	.142	.276	.169	.213	.874		
Shoulder_width	Pearson Correlation	.230	.274	-.471**	.565**	.136	-.123	.271	1
	Sig. (2-tailed)	.171	.101	.003	.000	.421	.466	.105	

Table 4.7 Model Summary for mid of curve: Model II Step II

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	31.912	1.339		23.829	0.000
Radius (R)	0.105	0.013	0.801	7.925	0.000

Table 4.7 shows the parameter estimates for the final model for mid of curve with Radius as the only predictor variable. The variable is considered as a significant predictor as it falls within the 95% confidence interval (Sig<0.05). The final model obtained is:

$$V85\ (MC) = 31.912 + 0.105R$$

As shown in Table 4.8, R-Squared Value was obtained as 0.642 i.e. 64.2% of variance of original field data is explained by the variance of field data obtained.

Table 4.8 R-Squared Values: Model II

R	R-Squared	Adjusted R-Squared	Std. Error of the Estimate
0.801	0.642	0.632	5.716

For the case of mid of curve, radius and deflection angle were found to be significant at 95% confidence interval. The coefficients obtained are tabulated in Table 4.8.

4.1.3 End of Curve: Model III

For the case of end of curve, radius, deflection angle, length of curve and gradient were found to be significant at 95% confidence interval. The coefficients obtained are tabulated in Table 4.9.

Based on the Correlation Matrix obtained for Model III in Table 4.10, only radius was selected for the final model as the value of pearson correlation of V_{85} at end of curve with radius is higher than that with deflection angle at same level of significance of 0.000. Other two significant variables were also not included in the final model because of weak correlation with the dependent variable.

Table 4.9 Model Summary for end of curve: Model III Step I

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	14.322	17.066		0.839	0.0408
Radius	0.046	0.026	0.265	2.728	0.009
Deflection Angle	-0.199	0.060	-0.468	-3.336	0.002
Width	3.419	1.956	0.198	1.748	0.091
Length of curve	0.386	0.117	0.358	3.305	0.003
super elevation	0.098	0.735	0.012	0.133	0.895
Gradient	-0.530	0.234	-0.204	-2.266	0.031
Shoulder width	-3.412	3.311	-0.116	-1.030	0.311

Table 4.10 Correlation matrix for Model III

Parameters		EC	Radius	Deflection_ Angle	Width	Length_of_ curve	super_el evation	Gradient	Shoulder _width
EC	Pearson Correlation	1							
	Sig. (2-tailed)								
Radius	Pearson Correlation	.789**	1						
	Sig. (2-tailed)	.000							
Deflection _Angle	Pearson Correlation	-.748**	-.726**	1					
	Sig. (2-tailed)	.000	.000						

Parameters		EC	Radius	Deflection_ Angle	Width	Length_of_ curve	super_el evation	Gradient	Shoulder _width
Width	Pearson Correlation	.393*	.379*	-.455**	1				
	Sig. (2-tailed)	.016	.021	.005					
Length_of _curve	Pearson Correlation	.560**	.538**	-.257	-.010	1			
	Sig. (2-tailed)	.000	.001	.124	.954				
super_elev ation	Pearson Correlation	-.123	-.078	.189	-.204	.016	1		
	Sig. (2-tailed)	.467	.648	.262	.225	.924			
Gradient	Pearson Correlation	.037	.246	-.184	.231	.210	.027	1	
	Sig. (2-tailed)	.827	.142	.276	.169	.213	.874		
Shoulder_ width	Pearson Correlation	.281	.274	-.471**	.565**	.136	-.123	.271	1
	Sig. (2-tailed)	.092	.101	.003	.000	.421	.466	.105	

Table 4.11 Model Summary for end of curve: Model III Step II

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	38.130	1.813		21.029	0.000
Radius (R)	0.136	0.018	0.790	7.618	0.000

Table 4.11 shows the parameter estimates for the final model for end of curve with radius as the only predictor variable. The variable is considered as a significant predictor as it falls within the 95% confidence interval (Sig<0.05). The final model obtained is:

V_{85} (EC) = 38.13+ .136R

As shown in Table 4.12, R-Squared Value for Model III was obtained as 0.624 i.e. 64.2% of variance of original field data is explained by the variance of field data obtained.

Table 4.12 R-Squared Values: Model III

Model	R	R-Squared	Adjusted R-Squared	Std. Error of the Estimate
	0.790	0.624	0.613	7.740

4.2 Model Validation

Data obtained from other 10 horizontal curves (25% of the original data-set) where was used for model validation. The data is tabulated in Table 4.13.

Table 4.13 Model Validation Data-Set

Chainage (km)	Deflection angle	Length Horizontal Curve	Min_ Radius_of_ Curvature	Gradient	PreSC	PreMC	PreEC	ObsSC	ObsMc	ObsEC
10+128	76.000	27.000	20.355	-3.5	41.16	35.50	42.78	35.12	30.25	55.18
11+855	108.000	44.000	22.280	-9.3	42.57	36.42	43.97	40.01	35.65	74.10
12+058	105.000	27.000	15.000	-5.79	41.42	35.67	43.00	34.36	26.32	64.23
12+631	60.000	33.000	31.510	5.42	38.93	34.05	40.90	48.40	35.17	35.70
12+862	120.000	50.000	23.873	-4.92	51.79	42.44	51.77	35.62	26.56	65.01
13+276	78.000	45.000	33.055	-3.87	37.94	33.40	40.06	45.31	34.01	72.23
13+723	80.000	30.000	21.486	5.9	41.04	35.43	42.68	41.90	39.42	25.59
13+917	32.000	35.000	62.667	7.113	39.49	34.42	41.38	55.62	39.28	45.82
15+440	40.000	30.000	42.97	-4.58	40.97	35.38	42.63	51.51	40.59	72.21
15+900	80.000	32.000	22.92	-2.91	35.26	32.84	63.41	39.97	29.37	55.32

R-Squared Plots

i) **Start of Curve**

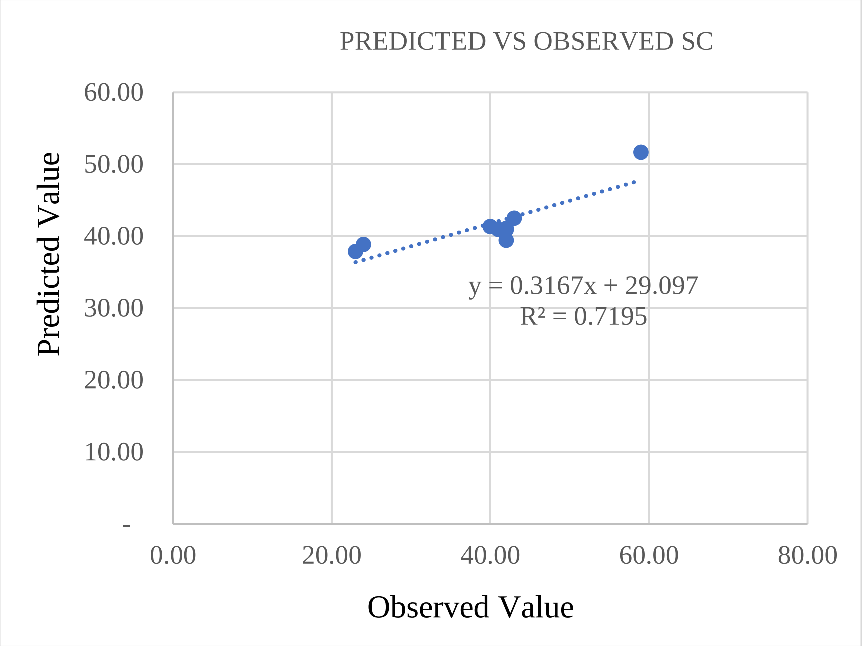

Figure 4.1 Predicted VS Observed Plot for SC

Regression analysis between observed value and predicted value of V_{85} operating speeds at the start of curve gave following results as per Figure 4.1 where R-Squared Value was obtained as 0.7195 (i.e. 71.95% of variance of original field data is explained by the variance of field data obtained from MLR equation).

The Equation obtained for the line of best fit:

Predicted Value at SC = 29.097 + .3167 * Observed Value

Similarly, regression analysis between observed value and predicted value of V_{85} at mid of curve gave R-Squared values of 0.6292 (i.e. 62.92% of variance of original field data is explained by the variance of field data obtained from MLR equation) as per Figure 4.2.

The Equation obtained for the line of best fit:

Predicted Value at MC = 25.497 + 0.2869 * Observed Value

ii) Mid of curve

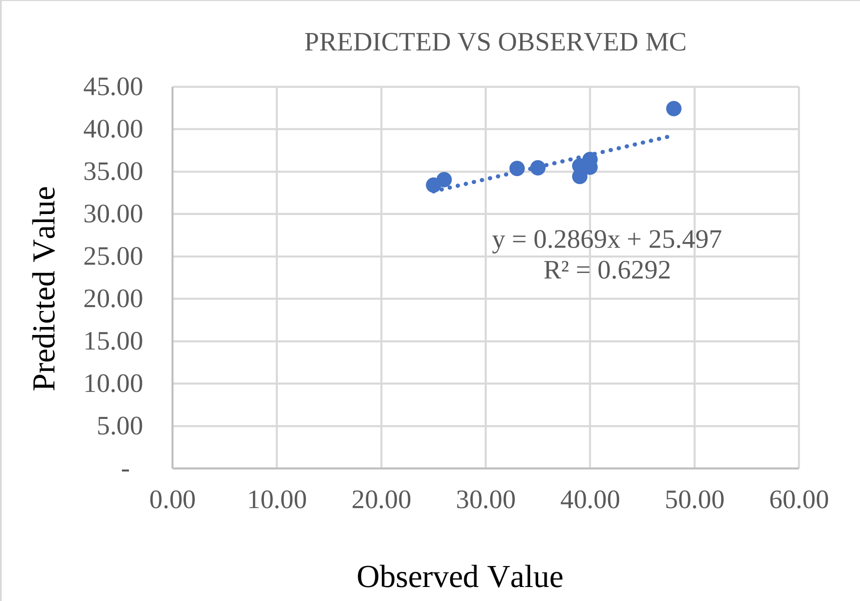

Figure 4.2 Predicted VS Observed Plot for MC

iii) End of curve

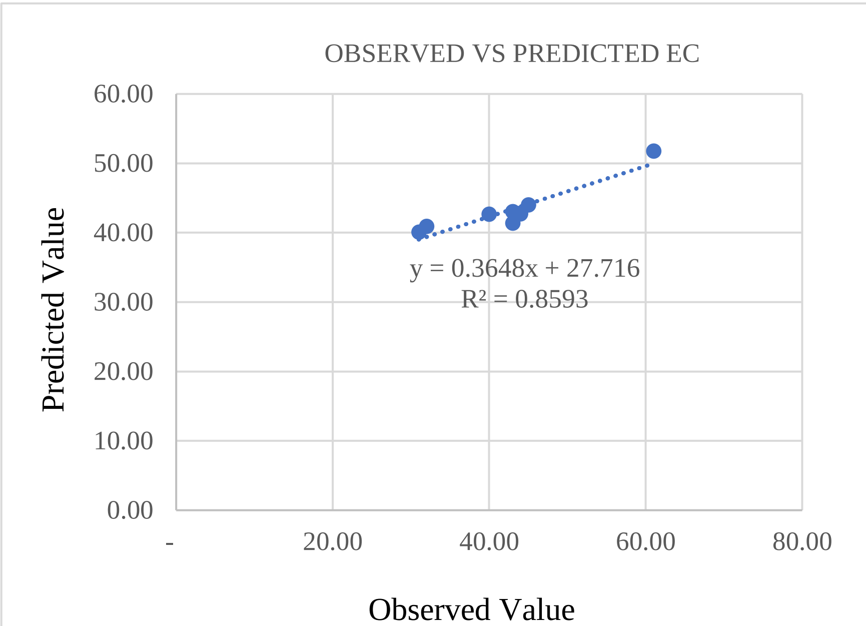

Figure 4.3 Predicted VS Observed Plot for EC

Regression analysis between observed value and predicted value of V_{85} at end of curve gave R-Squared values of 0.8593 (i.e. 85.93% of variance of original field data is explained by the variance of field data obtained from MLR equation) as per Figure 4.3.

The Equation obtained for the line of best fit:

Predicted Value at EC= 27.716+ 0.3648* Observed Value

From Figure 4.1, Figure 4.2 and Figure 4.3, it can be concluded that the values of R-Squared are within the acceptable range. The model showed best results in case of validation for end of curves.

Similarly, other tests of validation including MAE, MAPE, RMSE and Chi-Square tests were also conducted. The RMSE values were obtained as 4.6 km/hr, 4.81 km/hr and 5.03 km/hr at the start, mid and end of curve respectively, which signifies that the predicted data are slightly deviant from the regression line i.e. there is very little difference between the observed and the predicted data. Similarly, MAE and MAPE were calculated and returned values of 4.23, 3.84, 3.24 and 0.15, 0.12 and 0.08 respectively were obtained at start, mid and end of curve which are considered acceptable.

The values obtained for each of the validation tests are shown in Table 4.14.

Table 4.14 Summary of statistics for speed prediction validation tests

S.N.	Tests	SPE at SC	SPE2 at MC	SPE3 at EC
1	R-Squared	0.7195	0.6292	0.8593
2	MAE	4.23	3.84	3.24
3	MAPE	.15	0.12	0.08
4	RMSE	4.60	4.81	5.03
5	Chi Square Value	12	6.75	5.95
6	Chi Square Critical Value at 5% Significance	16.92	16.92	16.92

4.3 Remodeling Using Validation Data

Firstly, only 75% of the total data were used for developing the MLR model. Then the developed model was validated by next 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).

Summary of MLR Model with Validation Data

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

Regression Equations:

V85 (SC) =36.210+0.160*R eq (1)

V85 (MC) = 31.341+0.108*R eq (2)

V85 (EC) =38.13+ .136R eq (3)

R-Squared value of 0.70 (i.e. 70% of variance of original field data is explained by the variance of field data obtained from MLR equation) was obtained for start of curve while the R-Squared value for mid of curve was obtained as 0.64. For end of curve, the R-Squared value was found out to be 0.62. Figure 4.4 shows the scatter plots of Observed VS Predicted Values for the full model including complete data-set of 47 curves.

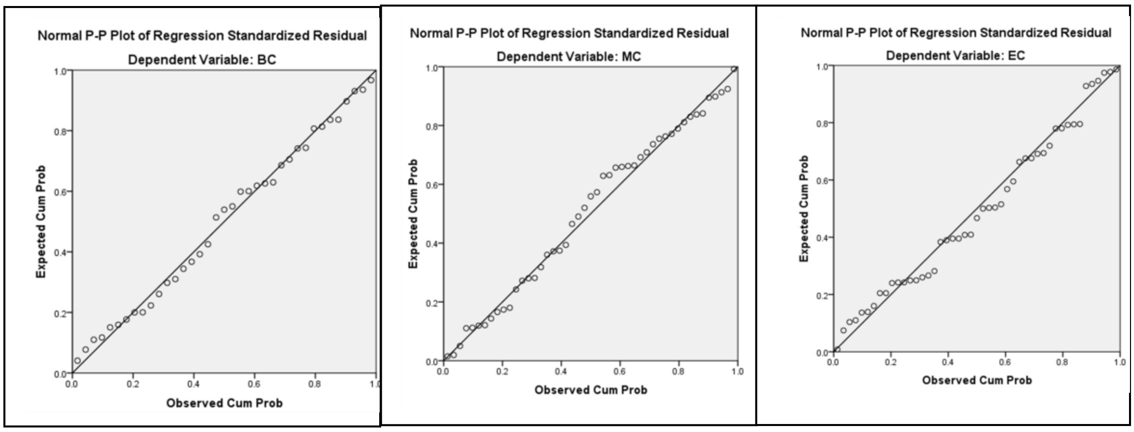

Figure 4.4 Expected & observed variation and normal scatter plots

CHAPTER FIVE: RESULT AND DISCUSSIONS

The research was performed to explore the relationship between the operating speed of vehicles with the geometric features in the two-lane national highway. Following results were drawn based on the study:

1. The developed models along with the comparison with existing design speed are tabulated below in Table 5.1. The range of radius of curvature used in the stretches lies between 15m to 400 m. For the sample of 0+190 km chainage with radius (R) as 34.21 m, we find out the value of V_{85} as follows using the model will be as shown in table no 5.1

Table 5.1 Comparison of Existing Design Speed and Predicted Speed

V_{85}(SC)	Existing Design Speed	30 km/hr	
	Predicted Speed (R=34.21 m)	36.210+0.160*R=	42 km/hr
V_{85}(MC)	Existing Design Speed	30 km/hr	
	Predicted Speed (R=34.21 m)	31.341+0.108*R	35km/hr
V_{85}(EC)	Existing Design Speed	30 km/hr	
	Predicted Speed (R=34.21 m)	38.13+ .136*R	42.78km/hr

Since the design speed in the curves was 30km/hr as per DoR (2013) and the operating speed calculated was 42km/hr for start of curve, 35km/hr for mid of curve and 42.78 km/hr for end of curve. As per the values obtained, we can ascertain that the operating speeds of the vehicles do not comply with the design speed standards. The deviation is especially higher in start and end of curves. The above results point towards the need to replace the equation of design speed with the obtained values of V_{85} Speed.

2. Compared to results of Summary of Equations Developed by (Qureshi, Khakheli and Memon, 2005) from Pakistan Road Section Regression Equation was:

$V_{85} = 60.0 + 0.0551 * R$ (I) with R^2 0.98

$V_{85} = 68.8 + 0.0405 * R$ (II) with R^2 0.85

$V_{85} = 53.4 + 0.0289 * R – 0.446 * D + 0.27 * Lc$ (III) with R^2 0.81

The models obtained from my research were found to be similar to the above models in terms of the predictor variable even though the geographical terrain of the roadways used to develop the models were different.

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 85^{th} percentile curve speed ranged from 8.9 to 13 percent. Overall, the performance of the equations showed a MAPE of 11.5 percent.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

The data analysis started with preparation and the checks for correlations. It was followed by the identification of the independent variables that were correlated with 85th percentile speed. Then a series of statistical procedures were applied to the data to identify the best combination of variables to predict V_{85}. The variables selected in the initial analyses were used to refine and select the regression models for vehicle speeds on the different alignment. Among different variables, length of curve, super elevation, shoulder width, gradient and carriageway width did not show good statistical significance when analyzed. The radius of curvature was found out to be the most influential parameter in determining the operating speed. The models developed for start, mid and end of curve accounted for nearly 70.2% 64.3% and 62.6% of the variance in the data respectively. Since generally R^2 values of above 0.5 represent good data fit, the models developed can be considered having good predictive potential, which were further confirmed by Chi-square test, MAPE and RMSE tests.

The following recommendations are made based upon the findings from this study:

1. The result of the study will be useful in redesigning the horizontal curves by considering operating speed.
2. Further study is necessary to validate the operating speed relation with geometric parameters using data from other road sections.

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APPENDICES

APPENDIX A:

FIELD SURVEY DATA

APPENDIX B:

GEOMETRIC DATA CALCULATION

APPENDIX C:

CALCULATION SHEET OF OBSERVED DATA VS PREDICTED DATA

APPENDIX D:

CALCULATION SHEET FOR MAE, MAPE, MSE AND RMSE

APPENDIX A: FIELD SURVEY DATA

	SC	MC	EC	SC, MC	MC, EC	SC, EC	Length of Curve	Gradient	E1	E2	E3	Difference	Width	Super elevation	Deflection Angle
Curve 1	1.060	2.096	2.570	-1.04	-0.47	-1.51	40.00	-4.58	0.08	0.12	0.08	0.09	7.40	1.25	67.00
	0.840	1.860	2.670	-1.02	-0.81	-1.83									
	0.982	2.220	2.494	-1.24	-0.27	-1.51									
Curve 2	0.280	1.615	3.190	-1.34	-1.58	-2.91	30.00	-10.70	0.00	0.26	0.35	0.20	7.00	2.88	40.00
	0.160	1.785	3.370	-1.63	-1.59	-3.21									
	0.285	1.870	3.535	-1.59	-1.67	-3.25									
Curve 3	1.230	1.740	2.050	-0.51	-0.31	-0.82	25.00	-3.50	0.25	0.32	0.20	0.26	7.90	3.24	40.00
	1.295	1.925	2.170	-0.63	-0.25	-0.88									
	1.480	2.058	2.250	-0.58	-0.19	-0.77									
Curve 4	2.402	2.612	2.885	-0.21	-0.27	-0.48	27.00	-2.65	0.08	0.53	0.36	0.32	8.00	4.00	76.00
	2.425	2.690	3.140	-0.27	-0.45	-0.72									
	2.480	3.140	3.240	-0.66	-0.10	-0.76									
Curve 5	1.059	1.988	2.093	-0.93	-0.11	-1.03	35.00	-5.79	0.33	0.26	0.58	0.39	8.40	4.63	20.00
	0.805	1.840	2.832	-1.04	-0.99	-2.03									
	0.730	1.726	2.670	-1.00	-0.94	-1.94									
Curve 6	0.802	1.886	2.960	-1.08	-1.07	-2.16	26.00	-9.89	0.12	0.30	0.48	0.30	7.30	4.15	105.00
	0.950	2.192	3.521	-1.24	-1.33	-2.57									
	0.925	2.188	3.443	-1.26	-1.26	-2.52									
Curve 7	3.120	4.300	5.230	-1.18	-0.93	-2.11	45.00	-4.92	0.40	0.30	0.04	0.25	7.00	3.52	77.00
	3.000	4.178	5.213	-1.18	-1.04	-2.21									
	2.718	4.000	5.193	-1.28	-1.19	-2.48									
Curve 8	0.530	1.665	2.654	-1.14	-0.99	-2.12	50.00	-3.87	0.30	0.09	0.07	0.15	7.20	2.14	120.00
	0.675	1.725	2.610	-1.05	-0.89	-1.94									
	0.834	1.750	2.581	-0.92	-0.83	-1.75									
Curve 9	4.020	2.332	1.210	1.69	1.12	2.81	45.00	5.91	0.27	0.95	0.46	0.56	7.40	7.56	78.00
	4.080	2.910	1.420	1.17	1.49	2.66									
	4.290	3.280	1.670	1.01	1.61	2.62									
Curve 10	3.450	2.620	1.402	0.83	1.22	2.05	30.00	7.11	0.17	0.41	0.35	0.31	7.90	3.91	80.00
	3.339	2.340	1.205	1.00	1.14	2.13									

	SC	MC	EC	SC, MC	MC, EC	SC, EC	Length of Curve	Gradient	E1	E2	E3	Difference	Width	Super elevation	Deflection Angle
	3.280	2.215	1.050	1.07	1.17	2.23									
Curve 11	0.080	1.245	2.593	-1.17	-1.35	-2.51	35.00	-6.84	0.37	0.20	0.12	0.23	8.20	2.76	32.00
	0.245	1.305	2.640	-1.06	-1.34	-2.40									
	0.445	1.440	2.713	-1.00	-1.27	-2.27									
Curve 12	2.950	1.740	1.538	1.21	0.20	1.41	38.00	5.46	0.25	0.26	0.10	0.20	8.30	2.43	74.00
	3.335	2.370	1.260	0.97	1.11	2.08									
	3.200	2.000	1.442	1.20	0.56	1.76									
Curve 13	2.120	1.915	1.685	0.21	0.23	0.44	30.00	1.92	0.26	0.05	0.05	0.12	7.12	1.69	38.00
	2.240	2.050	1.665	0.19	0.39	0.58									
	2.380	1.865	1.635	0.52	0.23	0.75									
Curve 14	1.780	1.757	1.865	0.02	-0.11	-0.09	42.00	0.15	0.40	0.42	0.36	0.39	8.30	4.73	108.00
	2.065	2.042	2.000	0.02	0.04	0.06									
	2.175	2.179	2.225	0.00	-0.05	-0.05									
Curve 15	0.235	0.860	1.180	-0.63	-0.32	-0.95	30.00	-2.91	0.29	0.24	0.31	0.28	7.70	3.62	85.00
	0.472	0.935	1.345	-0.46	-0.41	-0.87									
	0.521	1.100	1.490	-0.58	-0.39	-0.97									
Curve 16	2.154	1.800	1.600	0.35	0.20	0.55	32.00	1.98	0.48	0.60	0.39	0.49	7.90	6.19	80.00
	2.464	2.200	1.832	0.26	0.37	0.63									
	2.630	2.400	1.992	0.23	0.41	0.64									
Curve 17	3.520	2.550	1.742	0.97	0.81	1.78	32.00	5.42	0.23	0.29	0.28	0.27	9.00	2.97	26.00
	3.615	2.719	1.882	0.90	0.84	1.73									
	3.750	2.840	2.025	0.91	0.82	1.73									
Curve 18	0.610	1.402	3.020	-0.79	-1.62	-2.41	33.00	-5.87	0.05	0.24	0.14	0.14	8.70	1.64	60.00
	0.764	1.945	2.700	-1.18	-0.76	-1.94									
	0.665	1.639	2.885	-0.97	-1.25	-2.22									
Curve 19	1.285	2.278	2.960	-0.99	-0.68	-1.68	37.00	-4.59	0.51	0.29	0.45	0.42	9.00	4.62	25.00
	1.061	2.125	2.758	-1.06	-0.63	-1.70									
	0.778	1.985	2.513	-1.21	-0.53	-1.74									
Curve 20	2.863	1.586	0.330	1.28	1.26	2.53	46.60	5.66	0.19	0.23	0.22	0.21	8.50	2.47	41.00
	3.111	1.741	0.474	1.37	1.27	2.64									
	3.049	1.813	0.546	1.24	1.27	2.50									

	SC	MC	EC	SC, MC	MC, EC	SC, EC	Length of Curve	Gradient	E1	E2	E3	Difference	Width	Super elevation	Deflection Angle
Curve 21	1.267	1.195	1.215	0.07	-0.02	0.05	39.20	-0.55	0.37	0.23	0.20	0.26	9.20	2.87	67.00
	0.968	1.112	1.185	-0.14	-0.07	-0.22									
	0.896	0.968	1.020	-0.07	-0.05	-0.12									
Curve 22	0.227	0.752	1.401	-0.53	-0.65	-1.17	46.10	-2.55	0.16	0.25	0.19	0.20	9.30	2.14	41.00
	0.350	0.886	1.524	-0.54	-0.64	-1.17									
	0.391	0.999	1.586	-0.61	-0.59	-1.20									
Curve 23	2.276	1.730	1.020	0.55	0.71	1.26	49.30	2.68	0.33	0.35	0.24	0.31	8.40	3.63	32.00
	2.184	1.473	0.865	0.71	0.61	1.32									
	1.947	1.380	0.783	0.57	0.60	1.16									
Curve 24	0.587	0.608	0.577	-0.02	0.03	0.01	47.30	0.09	0.28	0.26	0.28	0.27	8.00	3.39	67.00
	0.783	0.783	0.742	0.00	0.04	0.04									
	0.865	0.865	0.855	0.00	0.01	0.01									
Curve 25	2.554	1.473	0.361	1.08	1.11	2.19	48.10	4.58	0.20	0.14	0.11	0.15	8.50	1.78	45.00
	2.637	1.504	0.433	1.13	1.07	2.20									
	2.750	1.617	0.474	1.13	1.14	2.28									
Curve 26	1.380	1.421	1.483	-0.04	-0.06	-0.10	48.10	-0.18	0.05	0.00	0.04	0.03	8.60	0.36	71.00
	1.478	1.463	1.566	0.01	-0.10	-0.09									
	1.329	1.421	1.524	-0.09	-0.10	-0.20									
Curve 27	0.700	1.524	2.359	-0.82	-0.84	-1.66	41.10	-4.18	0.16	0.16	0.17	0.16	8.60	1.91	73.00
	0.773	1.607	2.493	-0.83	-0.89	-1.72									
	0.536	1.360	2.194	-0.82	-0.83	-1.66									
Curve 28	2.925	1.844	0.587	1.08	1.26	2.34	41.10	5.59	0.23	0.23	0.15	0.20	8.10	2.50	29.00
	2.843	1.710	0.546	1.13	1.16	2.30									
	2.699	1.617	0.433	1.08	1.18	2.27									
Curve 29	3.646	2.194	0.433	1.45	1.76	3.21	49.40	6.53	0.24	0.23	0.14	0.20	7.30	2.78	50.00
	3.729	2.287	0.505	1.44	1.78	3.22									
	3.883	2.421	0.577	1.46	1.84	3.31									
Curve 30	0.608	1.524	2.307	-0.92	-0.78	-1.70	63.50	-2.55	0.31	0.52	0.53	0.45	7.20	6.25	77.00
	0.433	1.174	2.050	-0.74	-0.88	-1.62									
	0.299	1.009	1.782	-0.71	-0.77	-1.48									
	0.587	1.432	2.194	-0.85	-0.76	-1.61	52.30	-3.16	0.15	0.13	0.09	0.13	8.20	1.55	24.00

	SC	MC	EC	SC, MC	MC, EC	SC, EC	Length of Curve	Gradient	E1	E2	E3	Difference	Width	Super elevation	Deflection Angle
Curve 31	0.377	1.215	2.029	-0.84	-0.81	-1.65									
	0.433	1.298	2.101	-0.87	-0.80	-1.67									
Curve 32	3.440	1.998	0.433	1.44	1.57	3.01	48.20	6.30	0.26	0.25	0.22	0.24	9.10	2.64	8.00
	3.626	2.225	0.587	1.40	1.64	3.04									
	3.698	2.245	0.649	1.45	1.60	3.05									
Curve 33	0.608	0.999	1.288	-0.39	-0.29	-0.68	49.90	-1.18	0.35	0.29	0.28	0.31	8.00	3.81	15.00
	0.845	1.154	1.432	-0.31	-0.28	-0.59									
	0.956	1.288	1.566	-0.33	-0.28	-0.61									
Curve 34	0.227	0.587	1.009	-0.36	-0.42	-0.78	59.60	-1.42	0.35	0.42	0.41	0.39	9.10	4.34	18.00
	0.762	1.226	1.607	-0.46	-0.38	-0.85									
	0.577	1.009	1.421	-0.43	-0.41	-0.84									
Curve 35	2.647	1.720	0.670	0.93	1.05	1.98	59.70	3.50	0.26	0.08	0.14	0.16	8.50	1.90	14.00
	3.049	2.039	0.958	1.01	1.08	2.09									
	2.905	1.803	0.814	1.10	0.99	2.09									
Curve 36	0.608	0.917	1.195	-0.31	-0.28	-0.59	79.20	-0.87	0.27	0.29	0.19	0.25	6.30	3.93	24.00
	0.433	0.742	1.123	-0.31	-0.38	-0.69									
	0.340	0.628	1.009	-0.29	-0.38	-0.67									
Curve 37	0.649	1.627	2.616	-0.98	-0.99	-1.97	46.10	-4.47	0.32	0.30	0.31	0.31	9.00	3.43	87.00
	0.391	1.380	2.451	-0.99	-1.07	-2.06									
	0.330	1.329	2.307	-1.00	-0.98	-1.98									

APPENDIX B: GEOMETRIC DATA CALCULATION

Curve No.	Bearing1	Bearing2	Deflection	Width	LOC	Radius	Tangent	External Distance	Middle Ordinate	Chord Length	Shoulder Width	Gradient	Super Elevation
1	140	27	67	7.40	40.00	34.21	22.64	6.81	5.68	37.76	0.40	-4.58	1.25
2	135	355	40	7.00	30.00	42.97	15.64	2.76	2.59	29.39	0.30	-10.70	2.88
3	150	10	40	7.90	25.00	35.81	13.03	2.30	2.16	24.50	0.90	-3.50	3.24
4	316	212	76	8.00	27.00	20.36	15.90	5.48	4.32	25.06	1.00	-2.65	4.00
5	110	270	20	8.40	35.00	100.27	17.68	1.55	1.52	34.82	1.40	-5.79	4.63
6	115	190	105	7.30	26.00	14.19	18.49	9.12	5.55	22.51	0.30	-9.89	4.15
7	75	178	77	7.00	45.00	33.48	26.63	9.30	7.28	41.69	0.50	-4.92	3.52
8	180	240	120	7.20	50.00	23.87	41.35	23.87	11.94	41.35	0.20	-3.87	2.14
9	78	180	78	7.40	45.00	33.06	26.77	9.48	7.37	41.60	0.40	5.91	7.56
10	80	180	80	7.90	30.00	21.49	18.03	6.56	5.03	27.62	0.90	7.11	3.91
11	80	292	32	8.20	35.00	62.67	17.97	2.53	2.43	34.55	1.20	-6.84	2.76
12	210	316	74	8.30	38.00	29.42	22.17	7.42	5.92	35.41	1.30	5.46	2.43
13	132	350	38	7.12	30.00	45.23	15.58	2.61	2.46	29.45	1.20	1.92	1.69
14	175	103	108	8.30	42.00	22.28	30.67	15.63	9.18	36.05	1.30	0.15	4.73
15	230	135	85	7.70	30.00	20.22	18.53	7.21	5.31	27.32	0.70	-2.91	3.62
16	215	315	80	7.90	32.00	22.92	19.23	7.00	5.36	29.46	0.90	1.98	6.19
17	117	323	26	9.00	32.00	70.52	16.28	1.85	1.81	31.73	2.00	5.42	2.97
18	290	170	60	8.70	33.00	31.51	18.19	4.88	4.22	31.51	1.70	-5.87	1.64
19	120	325	25	9.00	37.00	84.80	18.80	2.06	2.01	36.71	1.70	-4.59	4.62
20	163	296	41	8.50	46.60	65.12	34.95	4.40	4.12	45.61	1.50	5.66	2.47
21	153	40	67	9.20	39.20	33.52	10.77	6.68	5.57	37.00	1.50	-0.55	2.87
22	157	296	41	9.30	46.10	64.42	24.09	4.36	4.08	45.12	1.20	-2.55	2.14
23	146	328	32	8.40	49.30	88.27	45.71	3.56	3.42	48.66	0.90	2.68	3.63
24	141	28	67	8.00	47.30	40.45	14.41	8.06	6.72	44.65	1.20	0.09	3.39
25	180	45	45	8.50	48.10	61.24	19.20	5.05	4.66	46.87	1.00	4.58	1.78

Curve No.	Bearing1	Bearing2	Deflection	Width	LOC	Radius	Tangent	External Distance	Middle Ordinate	Chord Length	Shoulder Width	Gradient	Super Elevation
26	212	321	71	8.60	48.10	38.82	29.00	8.86	7.22	45.08	0.90	-0.18	0.36
27	206	313	73	8.60	41.10	32.26	21.96	7.87	6.33	38.38	1.00	-4.18	1.91
28	129	337	29	8.10	41.10	81.20	54.27	2.67	2.59	40.66	0.90	5.59	2.50
29	165	294	50	7.30	49.40	56.61	19.71	5.85	5.30	47.85	1.00	6.53	2.78
30	216	319	77	7.20	63.50	47.25	24.91	13.13	10.27	58.83	1.00	-2.55	6.25
31	169	325	24	8.20	52.30	124.86	31.88	2.79	2.73	51.92	1.10	-3.16	1.55
32	158	329	8	9.10	48.20	345.21	20.33	0.84	0.84	48.16	1.00	6.30	2.64
33	91	286	15	9.00	49.90	190.60	32.16	1.64	1.63	49.76	1.00	-1.18	3.81
34	79	241	18	9.10	59.60	189.71	7.21	2.36	2.34	59.36	1.00	-1.42	4.34
35	98	292	14	8.50	59.70	244.33	24.42	1.83	1.82	59.55	1.70	3.50	1.90
36	103	308	24	7.00	79.20	189.08	36.11	4.22	4.13	78.62	1.50	-0.87	3.93
37	124	31	87	7.00	46.10	30.36	13.64	11.49	8.34	41.80	1.10	-4.47	3.43

APPENDIX C: CALCULATION SHEET OF OBSERVED DATA VS PREDICTED DATA

Curve no.	Deflection angle	Length of Horizontal Curve	Min Radius	Grade	Psc	Pmc	Pec	Osc	Omc	Oec
38	76	27	20.36	-3.5	41.16	35.5	42.78	35.12	30.25	55.18
39	108	44	22.28	-9.3	42.57	36.42	43.97	42	32	74.1
40	105	27	15	-5.79	41.42	35.67	43	34.36	26.32	64.23
41	60	33	31.51	5.42	38.93	34.05	40.9	48.4	38	34.08
42	120	50	23.87	-4.92	51.79	42.44	51.77	35.62	26.56	65
43	78	45	33.06	-3.87	37.94	33.4	40.06	45.31	36	74.64
44	80	30	21.49	5.9	41.04	35.43	42.68	41.9	38.12	26.12
45	32	35	62.67	7.113	39.49	34.42	41.38	53.28	35.23	45.82
46	40	30	42.97	-4.58	40.97	35.38	42.63	50.13	40.59	70.23
47	80	32	22.92	-2.91	41.16	35.5	42.78	36.54	30.02	55.32

APPENDIX D: CALCULATION SHEET FOR MAE, MAPE, MSE AND RMSE

Curve no.	ABSsc * (P-O)	ABSmc * (P-O)	ABSec * (P-O)	ABSsc * (P-O) ^ 2	ABSmc * (P - O) ^ 2	ABSec * (P - O) ^ 2	ABS (Osc - Psc) / Osc	ABS (Omc - Pmc) / Omc	ABS (Oec-Pec) / Oec
38	0.73	2.96	8.84	0.53	8.76	78.2	0.02	0.1	0.16
39	9.53	2.92	19.62	8.54	8.54	384.83	0.23	0.09	0.26
40	6.56	2.68	2.53	7.2	7.2	6.38	0.19	0.1	0.04
41	7.86	1.94	3.38	3.76	3.76	11.42	0.16	0.05	0.1
42	3.98	1.03	7.15	1.05	1.05	51.15	0.11	0.04	0.11
43	5.22	2.23	4.26	4.98	4.98	18.16	0.12	0.06	0.06
44	7.31	5.37	8.7	28.83	28.83	75.72	0.17	0.14	0.33
45	3.8	6.58	1.1	43.31	43.31	1.21	0.07	0.19	0.02
46	5.23	1.12	20.76	1.26	1.26	431.1	0.1	0.03	0.3
47	1.28	2.82	8.09	7.97	7.97	65.47	0.04	0.09	0.15
Sum	51.5	29.65	84.43	107.43	115.66	1123.64	1.21	0.89	1.53
Averge	4.23	3.84	3.24	10.743	11.566	12.364	0.15	0.12	0.08
MAEsc	4.23								
MAEmc	3.84								
MAEmc	3.24								
MSEsc	10.743								
MSEmc	11.566								
MSEec	12.364								
MAPEsc	0.15								
MAPEmc	0.12								
MAPEec	0.08								
RMSEsc	4.60								
RMSEmc	4.81								
RMSEec	5.03								