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Estimation of operating speed on two lane two way roads along N-65 (SIBI –Quetta)

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Abstract

Present study is an extension of earlier work carried out on two-lane two way roads in the two provinces of Pakistan i.e. N-25, N-55 and N-5 regarding the measure of operating speed and development of operating speed prediction models. Curved sections of two-lane rural highways are the main location of run-off road accidents. In addition to that the road alignment having combination of geometric elements may be more harmful to the drivers than the successive features with adequate separation. This study is carried out on two-lane two- way road along N-65 (from Sibi to Quetta). Three sections are selected for study with thirty three horizontal curves. Continuous speed profile data was recorded with the help of VBox (GPS based device) which was attached with a vehicle to detect vehicle position through satellite signals. VBox is new equipment with modern technology in this field and it helps in recording continuous speed profile and saving of this information on the computer as a permanent record. Through the regression analysis, models were developed for estimation of operating speed on horizontal curves and on tangent, and estimation of maximum speed reduction from tangent to curve. The validation of developed model shows compatibility with the experimental data.

Keywords: Operating speed, Speed profile, Design consistency

1. Introduction

Road transportation overwhelmingly dominates the other modes of transport systems. Apparently transportation by road is the backbone or lifeline of economy of a country like Pakistan.

The total length of road network in the country is approximately 258,000 Kilometers consisting of about 153,000 of paved roads (high type) and 105,000 Kilometer of gravel roads (Low Type). The length of National Highways is 11,900 Kilometer which is only 3.7% of the entire road network of the country, but NHA roads carry more than 80% of the country's traffic [1].

Research has revealed that the curved sections of two-lane rural highways are the main location of run-off accidents. The combination of geometric features increases driver work load and may be more hazardous to the drivers than successive features with adequate separation [2].

The basic objective in geometric design is to provide smooth traffic flowing, facility into two main parts. Vertical curves and Horizontal Curves using guidelines provided by AASHTO, and Engineer can design a roadway that is comfortable, safe and appealing to the eye [3]. The most common measures which are being considered useful in evaluating consistency of geometric elements are operating speed, vehicle stability, alignment indices and driver workload.

1.1 Discrepancy in the design and operating speed

A common practice has been to set speed limits at the 85th percentile of operating speeds, but it is observed that operating and design speeds are often not in agreement and operating speed that are inconsistent can create potential safety problems [2].

Disparity between design and operating speeds mostly occurs on the class of the highway where volume is relatively low (rural, two-lane minor arterioles and collectors, in level to rolling terrain) with design speed less than 95 km/h. Pakistan highway network consists of more than 70 % of such roads. It is very essential to note that the operating speeds did

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not remain consistent with regard to design speeds in different countries especially in Pakistan, as observed from the researches conducted. Majority of two-lane two way traffic roads in Pakistan are being operated with a design speed of less than or equal to 90 km/h. Therefore it is necessary to develop model for estimation of operating speed and to rectify inconsistent local spots to ensure efficient, safe and smooth traffic operation [2].

1.2 Design consistency evaluation

In order to improve the road safety, the evaluation of design consistency provides a tool for highway designers. The earlier researchers have identified four major techniques for measuring design consistency i.e.

i) Operating Speed
ii) Vehicle Stability
iii) Alignment Indices
iv) Driver Workload

Design consistency refers to design that conforms to what drivers expect. There are several approaches that can be considered for design consistency evaluation namely operating speed, vehicle stability, driver work load, and alignment indices [4, 5].

The rural highway design policies in Australia, England, France, Germany, Switzerland include feedback loop, and a lot of research work that has already been carried out in this field by giving due consideration to revision of design policy, however the design policy in our country has not been revised as yet.

In Pakistan implementation of theoretical aspect is not possible, this is because researchers have not studied as yet various sections of highway to develop a unique model for country which can take in to account all local conditions of traffic behavior, driving conditions and road conditions.

Memon [2] studied experimentally behavior of traffic on composite curves of the road section and developed a prediction model for operating speed. Continuous Speed data was collected on some test section in two provinces of Pakistan. In order to develop a general model representing almost all the areas of the country it was recommended that more data should be collected in other parts of the country.

Hence, present study attempts to collect speed data on the study sections along N-65 (Sibi – Quetta).

2. Existing operating speed models

Most of previous studies have identified radius of the curve as influencing parameter in estimating operating speeds [2].

Glennon et al [6] studied operating speed on 56 alignments in four states. The study roadways were limited to high speed [80 to 105 km/h operating speeds] rural alignments with grades not exceeding 5 percent. Only passenger vehicles operating under free flow conditions were considered.

A statistical relationship between the 85th percentile speeds in horizontal curve and the degree of curve developed. The developed model was:

$$V_{85} = 103.96 - \frac{4524.94}{R} \qquad R^2 = 0.84, \qquad (1)$$

Lamm et al. [7] studied operating speed on 261 curves in New York State. The study sections were limited to two–lane rural alignments with grades not exceeding 5 percent and degree of curvature ranging from 0 to 27 degrees (∞ to 200 ft). Only passenger vehicles under free flow conditions were considered. They found that lane width, shoulder width and AADT explained only an additional 5 % of the variation in the expected operating speeds over a simple speed model that only considers degree of curve:

$$V_{85} = 94.398 - \frac{3188.656}{R} \qquad R^2 = 0.79, \qquad (2)$$

This model can be used to determine the tangent operating speed where $DC = 0$ ($R \rightarrow \infty$), and would produce an operating speed of 94.4 km ph.

Krammes et al. [8] developed a model to evaluate horizontal alignment consistency on two-lane rural highways. The model estimates V_{85} along the horizontal curve. The model was based on the assumption that the speed was constant along horizontal curves. Acceleration and deceleration were assumed to occur only on tangents at a rate of 0.85 m/s^2 as suggested by Lamm et al. Based on data from 138 curved sections, the regression equation to determine V_{85} on the curve was:

$$V_{85} = 102.40 - 1.57(D) - 0.012(L_c) - 0.10(\Delta) \qquad R^2 = 0.82 \quad (3)$$

Misaghi and Hassan [9] developed operating speed model based on the data which they collected on 20 curves in Canada. A preliminary relationship was developed for operating speed on horizontal curves i.e.

$$V_{85} = 94.30 + 8.673 * 10^{-6}\left(R^2\right) \qquad R^2 = 0.524 \qquad (4)$$

Memon [2] developed operating speed prediction models based on the continuous operating speed data collected through VBox. Operating speed data was collected on 216 horizontal curves along different road alignments in two provinces of Pakistan. The models so developed were:

$$V_{85MC} = 40.4 - 1571\ 1/R - 0.613\, Max.V_{85T} + 0.0244\, L_c - 0.163\, I$$

$$R^2 = 0.84 \qquad (5)$$

$$Max V_{85T} = 111 + 0.0110\, L_T - 2757\ 1/R_1 - 12$$

$$R^2 = 0.615 \qquad (6)$$

As far as present study is concerned, it is an extension to earlier work, which was carried out by Memon [2]. This is because his study could not cover all the regions of the country, so those sections which are not carried in Memon study are being considered in this study. Once these results are available from most two-lane two-way sections of the country a unique model would be developed for prediction of operating speed for Pakistan.

3. Research methodology

In this study it was decided to use the same method as adopted by Memon [2] in his research. In this regard, continuous speed profile approach was used rather than collecting the spot speeds of separate samples of vehicles at different locations along a test section. VBox was attached with the vehicle to record the data.

The data was collected through the test driver method using the same equipped vehicle. Using such a data collection methodology, the chances of changes in driving behavior of drivers, non-free flow data collection condition and discontinuity in data collection due to sensor misses could be avoided.

In order to represent the local traffic and environmental conditions, study sites were selected along the National Highway N-65 connected two provinces of Pakistan. N-65 is an important National highway connecting Sukkur (3rd largest city of Sindh Province) with Quetta (capital of Balouchistan Province).

About 33 horizontal curves were selected with a wide range of geometric features.

Continuous speed data was collected for all the study sites in each (both) direction of traffic flow. Using the Statistical Software package (MINITAB Release 13.30), analysis were carried out to determine statistically the difference between data collected in two direction of traffic flow. The detailed analysis for Individual curve profile was also performed to bring out the detailed information of driver's driving capability including speed variations along the selected route.

Preliminary analysis of the data was conducted for preparing database for model development. Multiple linear regression method is used for 80 % of observed data, to develop the models for prediction of 85th percentile speed on horizontal curves and maximum reduction in the speed from straight section to mid of curve. Model selection was carried out according to Standard Error of Estimate (se) method.

The validation of finally selected models was also conducted using 20 % of observed data left for validation process. Validation process was undertaken through the comparison between the predicted and the observed operating speed values.

3.1 Site selection

In order to study the behavior of local traffic and environmental conditions, study sites were selected along the National Highways namely N-65 (Sibbi-Quetta) two provinces of Pakistan. Maximum parameters of planned study are achieved with the planned test sections of the road. In addition to that the geometric data was also obtained for the selected alignment i.e. N-65 with the compliance of following criteria.

(i) no intersection being adjacent to these sites;

(ii) no physical features being adjacent that may create unusual operating conditions or hazards;

(iii) grades less than 5 percent;

These criteria are similar to that which was used by previous researchers in this field [2, 5, 8].

Ordinary survey was carried out along the selected sections to meet the above requirement and limitations. About three test sections were selected having 33 curves (horizontal) with different configuration. The details of the selected test sections are presented in Table 1.

The alignment N-65 consisted various combinations, road parameters and vertical profile of less than or equal to 1%. Few test sections contained curves of radii greater than 450 m followed by long tangent, whereas few test sections contained curves of radii less than 300 m followed by tangents of smaller length. The alignment N-65 has the design speed of 90 km/h.

Fig. 1 presents the plan of test sections selected along N-65. The plans are given to show an idea about the combination of curves along the selected sections.

Table 1. Details of selected test sections along N-65 (sibi – quetta)

Section – I (371+00 to 378+00)

Curve No.	Chainage of P.C (m)	R (m)	D (deg)	Lc (m)	Chainage of P.T(m)	Approach Tangent Length (m)	Remarks
1	0 + 320	220	7.94	130	0 + 450	300	R/H
2	0 + 580	800	2.18	90	0 + 670	130	L/H
3	0 + 740	550	3.17	80	0 + 820	70	R/H
4	1 + 110	360	4.85	230	1 + 340	290	R/H
5	1 + 590	600	2.91	110	1 + 700	250	L/H
6	1 + 800	780	2.24	100	1 + 900	100	R/H
7	2 + 480	325	5.37	210	2 + 690	580	L/H
8	2 + 890	250	6.98	150	3 + 40	200	R/H
9	3 + 110	750	2.33	110	3 + 220	70	L/H
10	3 + 280	670	2.61	90	3 + 370	60	R/H
11	3 + 900	700	2.49	270	4 + 170	530	L/H
12	4 + 550	640	2.73	120	4 + 670	380	L/H
13	4 + 830	380	4.59	130	4 + 960	160	R/H
14	5 + 260	270	6.47	140	5 + 400	300	R/H
15	5 + 420	280	6.24	110	5 + 530	20	R/H
16	5 + 800	350	4.99	130	5 + 930	270	L/H
17	6 + 170	330	5.29	130	6 + 300	240	R/H
18	6 + 320	400	4.37	250	6 + 570	20	R/H
19	6 + 600	450	3.88	250	6 + 850	30	L/H

Section – II (250+00 to 258+00)

Curve No.	Chainage of P.C (m)	R (m)	D (deg)	Lc (m)	Chainage of P.T(m)	Approach Tangent Length (m)	Remarks
1	0 + 900	150	11.64	240	1 + 140	900	R/H
2	1 + 560	450	3.88	270	1 + 830	420	L/H
3	1 + 830	470	3.71	320	2 + 150	0	L/H
4	4 + 420	970	1.80	60	4 + 480	2270	R/H
5	5 + 270	750	2.33	130	5 + 400	790	R/H
6	6 + 70	340	5.14	390	6 + 460	670	L/H
7	6 + 610	140	12.47	200	6 + 810	150	R/H
8	6 + 930	380	4.59	170	7 + 100	120	L/H

Section – III (237+00 to 240+00)

Curve No.	Chainage of P.C (m)	R (m)	D (deg)	Lc (m)	Chainage of P.T(m)	Approach Tangent Length (m)	Remarks
1	0 + 590	780	2.24	90	0 + 680	590	R/H
2	0 + 790	280	6.24	150	0 + 940	110	L/H
3	0 + 960	610	2.86	110	1 + 70	20	R/H
4	1 + 230	440	3.97	80	1 + 310	160	R/H
5	2 + 130	330	5.29	150	2 + 280	820	L/H
6	2 + 690	170	10.27	240	2 + 930	410	L/H

4. Data collection and its analysis

The object of the data collection was to develop a comprehensive data base to establish the relationship between vehicle operating speed and geometric design elements along the roadway of two-lane rural highway. The data collection can be divided into operating speed data and roadway data.

4.1 Operating speed data

Vehicle operating speed data collection along all the selected test sections was carried out by test driver method, at day time under free flow and in fine weathering conditions. Twenty five test drivers were instructed to drive the equipped vehicle along the selected test sections in each direction of traffic flow.

At least 50 speed measurements have been taken on each study site for both directions.

4.2 85th percentile values of collected data

85th percentile values were obtained for real speed for each data base file through the analysis. Profiles were plotted for observed 85th percentile values for real speed, and vertical alignment of each test section in each direction of traffic flow.

These profiles represent the driver's choice of speed. Profiles were plotted using continuous real speed data obtained through VBox. These plots reflect speed trend along different combination of road elements and their effects on driver's speed.

Almost all speed data shows that operating speed remain above the designed speed on the curves with radius greater than 200m, where design speed is 90 km/h.

These profiles also identify the inconsistent locations or the location with abrupt / major changes in geometric elements. Fig. 2 to Fig. 4 is presenting the profiles of test sections along the selected study sections.

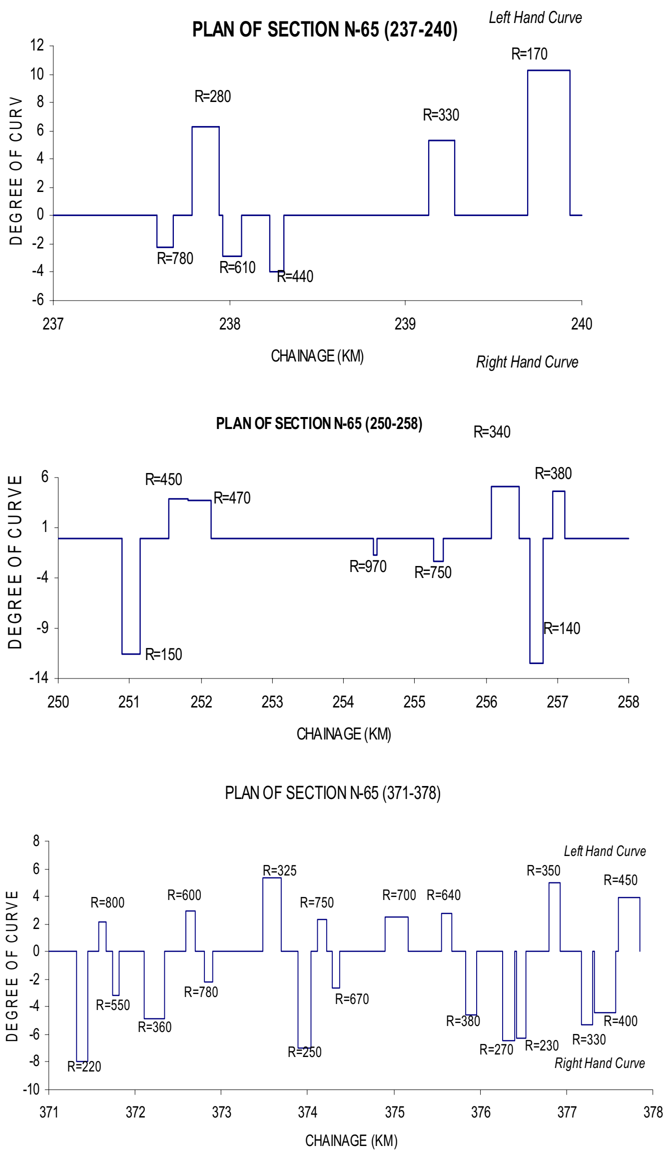


Fig. 1. Combination of curves on three test sections along N-65 (Sibi – Quetta)

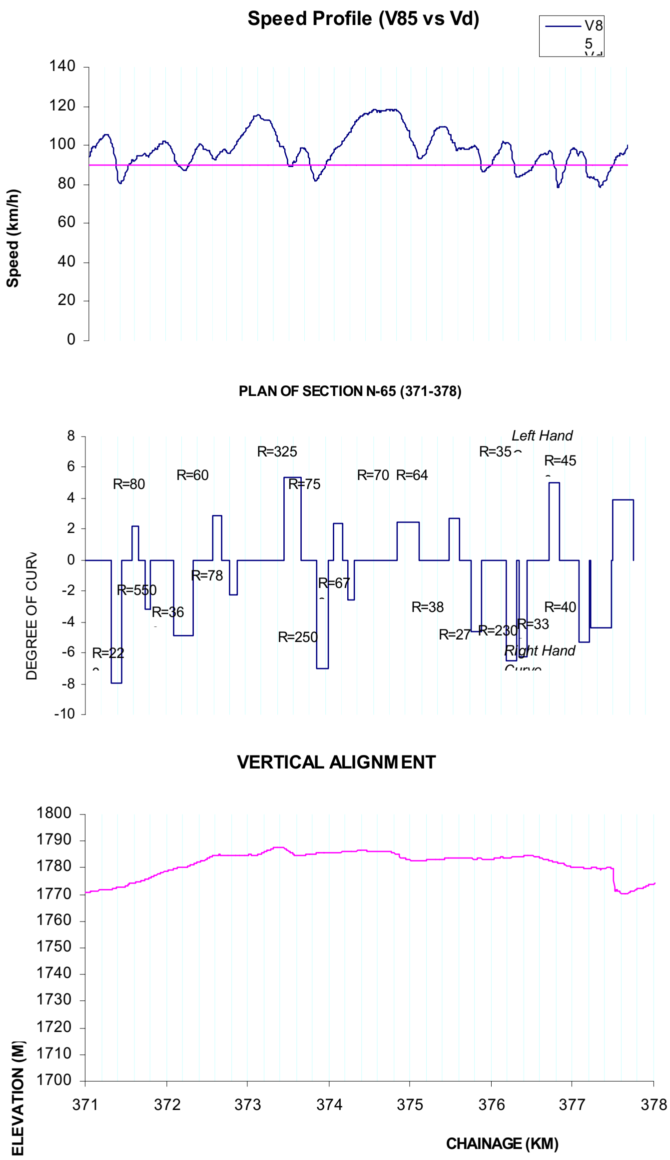


Fig. 2. Profiles of test section-I N-65 (371-378)

4.3. Descriptive statistical analysis

Using the Statistical Software package (MINITAB Release 13.30) the basic descriptive statistical analysis was carried out for the speed observations. Based on individual curve analysis, it was decided to develop model for prediction of speed on curve by taking in to consideration the data at mid of curve. Therefore descriptive statistical analysis was carried out for the speed observations at mid of curve only for different radii and Length of curves of the sections. The analysis included mean, standard deviation, 85th percentile and coefficient of variation. All the statistical analysis was conducted @ 95 % CI. The average coefficient of variation reported in present study comes to 0.10.

5. Development of models for prediction of 85th percentile speed on horizontal curves and tangent

The regression analysis of 85th percentile speeds, observed on horizontal curves and tangents, was carried out. Equations are developed using different variable used in earlier research such as; Radius of horizontal curve (*R*), length of curve (*Lc*), maximum 85th percentile speed on approach tangent ($Max.V_{85T}$) and inverse of radius of horizontal curve (1/R).

From the observed 85th percentile speeds at mid point of 63 horizontal curves along N-65 with different geometric characteristics. 80% data points were used for model development and 20% data points were left for model validation.

Statistical analysis reveals that the explanatory power of the model increases when two or more than two independent variables are used.

The models showing high R^2, F-value and t- value were selected for prediction of operating speed on horizontal curve V_{85MC}, maximum speed on tangent $Max.V_{85T}$

Taking the advantage of continuous speed data, efforts were also made to develop a model predicting the maximum speed reduction$V_{85}MSR$ while traveling from tangent to the curve.

The selected models along with their statistical results are shown as under:

$$V_{85MC} = 42.8 - 1.40\,D + 0.627\,Max.V_{85T} - 0.0224\,Lc$$
$$R^2 = 0.68 \qquad (7)$$

$$Max.\,V_{85T} = 88.6 + 0.00854\,R + 0.0119\,Lt + 0.0178\,Lc$$
$$R^2 = 0.58 \qquad (8)$$

$$V_{85}\,MSR = -\,69.0 + 0.68\,Max.\,V_{85T} + 1.61D - 0.0032\,Lt + 0.0078\,Lc$$
$$R^2 = 0.75 \qquad (9)$$

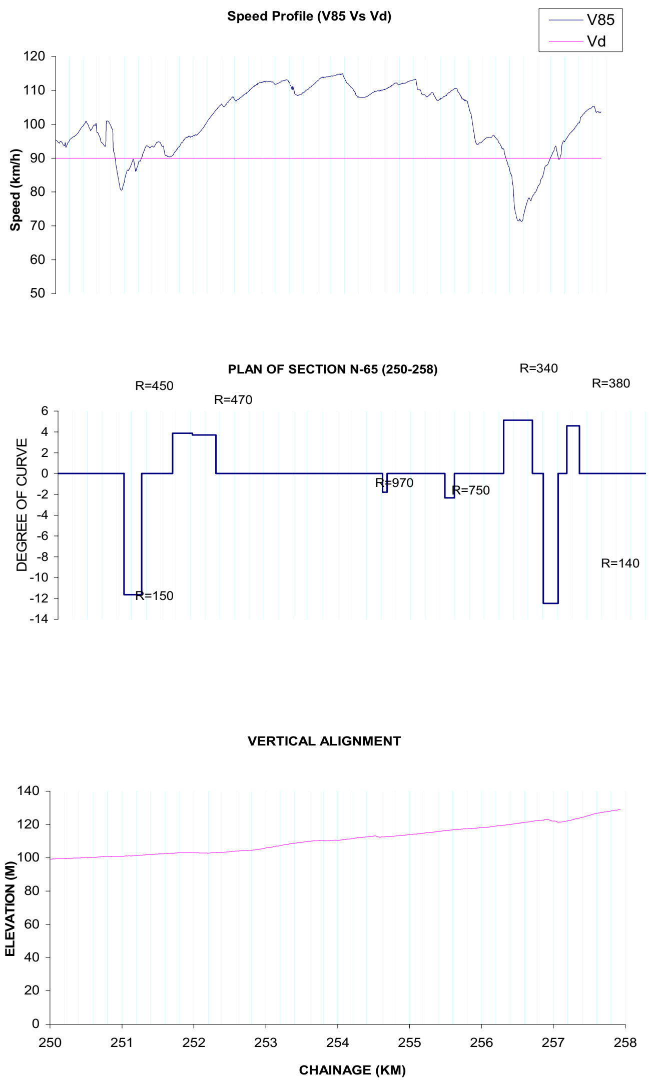


Fig. 3. Profiles of test section - II N-65 (250 - 258)

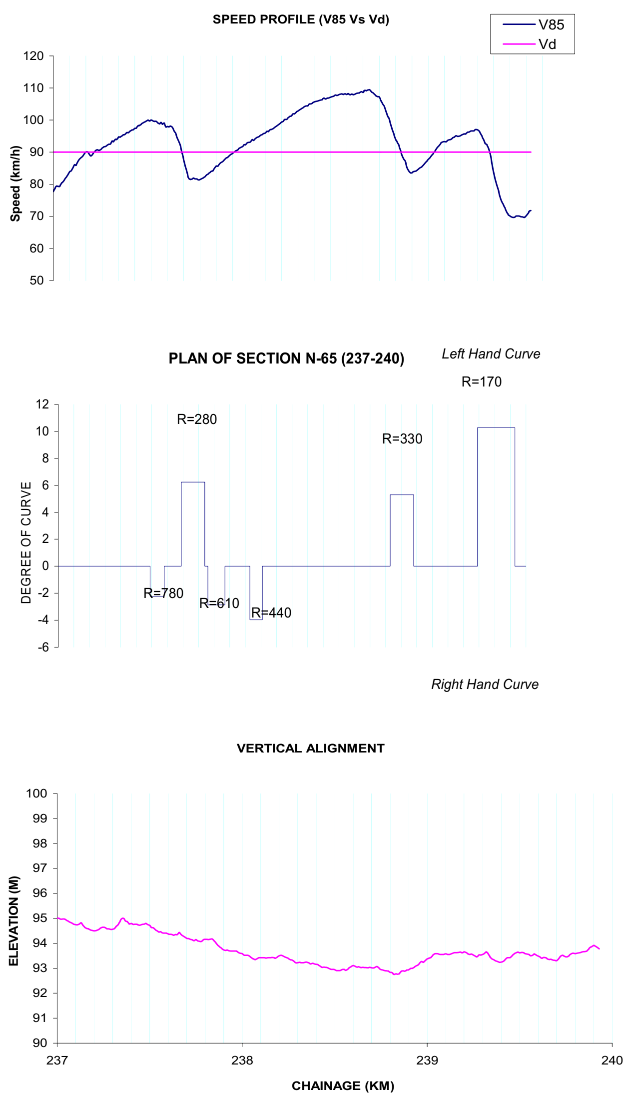


Fig. 4. Profiles of test section - III N-65 (237 - 240)

5.1 Validation of developed models for horizontal curves

Validation of developed regression models were carried out. A data set (20 % experimental data left for model validation) was used to compare the predicted V_{85MC}, Max. V_{85T}, and V_{85}MSR values to the actual V_{85MC}, Max. V_{85T}, and V_{85}MSR values.

Error of the Estimate σ_{est} is a measure of accuracy of predictions made with a regression line. The Standard Error of Estimate (σ_{est}) for selected models is then calculated with the following equations:

$$\text{Standard Error of Estimate } (\sigma_{est}) = (\sigma_{\text{est}}) = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - Y_i^{'}\right)^2}{n}}$$

Where: $Y_i{}'$ = predicted value for the ith validation observation

Y_i = actual value of ith validation observation

n = Total number of observations in the validation data set

A graphical comparison was also made between predicted and observed values of V_{85MC}, Max.V_{85T} and V_{85}MSR to check the relative difference. The comparison with the models showing the lowest σ_{est} values is given in Fig. 5 (a), (b) and (c).

The predicted values by the models developed in this study show the compatibility with the trend of experimental data.

Fig. 6 shows a graphical comparison of V_{85MC} values predicted by the model developed in this study and by other researchers, (i.e Lamm et al. 1987, Glennon et al. 1985, and Misaghi and Hassan, 2005) giving σest values of 10.57, 5.89, and 6.52 km/h respectively.

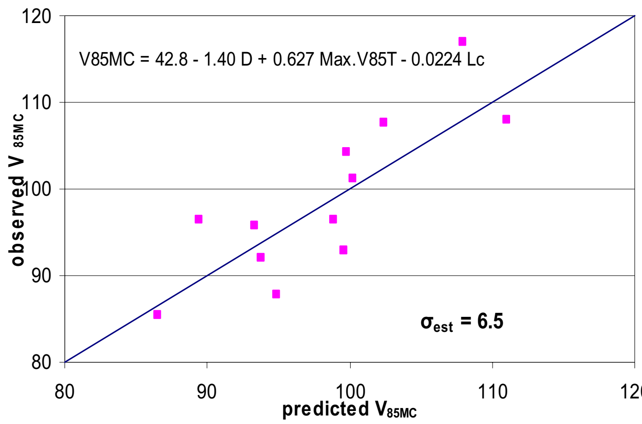
6. Conclusion

General conclusion of present research work can be drawn as under.

1. It was concluded that, drivers generally decelerate while approaching the curve and reaching their minimum speed at mid point of curve or near to it. Therefore in this study models are developed for prediction of speed at mid point of horizontal curves.

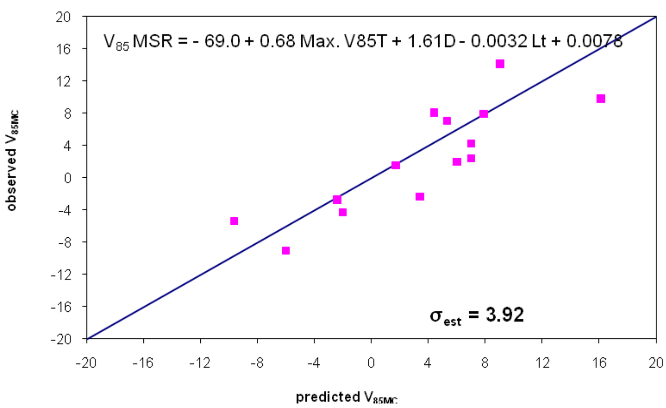
2. The regression analysis of 85th percentile speeds on horizontal curves was carried out for N-65. 80% data points were used for model development and 20% data points were utilized for validation of developed model.

3. Max. V_{85T} has the most significant influence on prediction



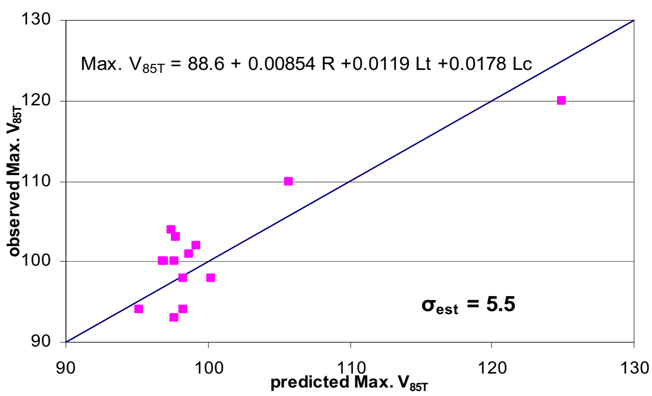
Observed V_{85MC} (km/h)	72	90	96	101	85	88	108	92	96	93	85	117	104	96	108
Predicted V_{85MC} (km/h)	80	74	93	100	78	95	102	94	89	100	87	108	100	99	111

Fig. 5 (a). Comparison of observed and predicted values of V_{85MC}



Observed V_{85}MSR (km/h)	22	-9	4	10	-3	14	2	8	-2	8	-5	2	-4	2	7
Predicted V_{85}MSR (km/h)	16	-6	7	16	-2	9	7	8	3	4	-10	6	-2	2	5

Fig. 5 (c). Comparison of Observed and predicted values of V_{85}MSR



Observed Max. V85T (km/h)	94	95	100	104	98	102	105	100	94	101	93	110	100	98	120
Predicted Max. V85T (km/h)	95	95	97	98	100	99	98	97	98	99	98	107	98	98	125

Fig. 5 (b). Comparison of Observed and predicted values of Max. $_{85T}$

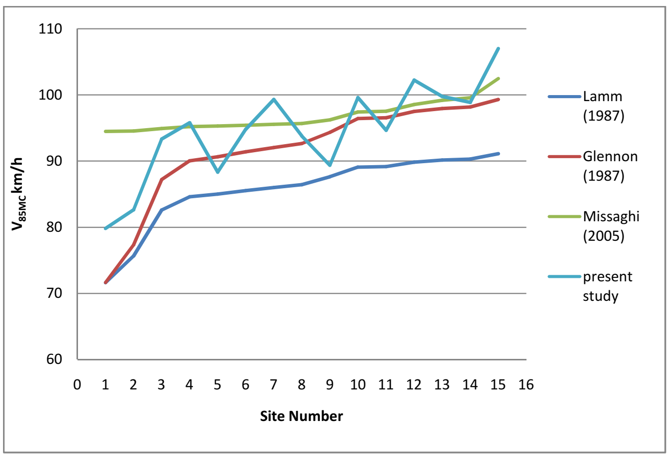


Fig. 6. Comparison of the predicted values of V_{85MC} from model developed in this study and with those from previous research

of V_{85MC}. The Degree of curve and length of curve are other most significant variables affect V_{85MC}. This solicits the earlier findings of Memon who carried his research work in Pakistan.

4. Developed Model of present work for prediction of maximum speed reduction from tangent to curve (V_{85}MSR) helps in the evaluating design consistency.

5. Error of estimate (se) calculated in the present study is slightly higher as compared to the error of estimate (se) calculated by Memon in Pakistan. This is due to limitation of data collection and change in speed profiles obtained for selected test sections. A similar sort of findings has been observed with the coefficient of determination (R^2).

6. While validating the model, the predicted values of V_{85MC}, Max. V_{85T} and V_{85}MSR showed reasonable compatibility with experimental data.

7. Findings of present study regarding operating speed on critical sections where we have mainly frequent occurrence of accident warns to fix warning sign board well ahead of horizontal curve to suggest drivers to reduce speed.

Recommendations for future research

In this study, models are have been developed for prediction of 85th percentile speed on mid of curve and maximum speed reduction from tangent to curve.

The speed prediction models developed in this study are based on continuous real speed data collected on local rural roads and is a major step towards the development of nationally applicable speed profile model. It is recommended to select more study sites in other provinces of the Pakistan for further analysis and modeling.

It is also recommended that the work carried out in this study and study made by Memon [2] should be compiled to develop more general model which should represent the local driver and traffic behavior of the country and can be used and a general guide lines to check deign consistency at the designing stage.

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Notation

V_{85} = 85th percentile curve speed (km/h)
R = Radius of horizontal curve (m)
R^2 = Coefficient of determination
D = Degree of curvature (deg)
Δ = Deflection angle (deg)
$Max.V_{85T}$ = Maximum 85th percentile speed on tangent (km/h)
V_{85MC} = 85th percentile speed on mid of curve (km/h)
R_1 = Radius of preceding horizontal curve (m)
R_2 = Radius of succeeding horizontal curve (m)
L_t = Length of tangent (m)
I = Deflection angle (degree)
L_c = Length of curve (m)