

TWO-LANE HIGHWAY CAPACITY ESTIMATION BASED ON GEOMETRIC FEATURES

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Abstract

The majority of roads in most countries are two-lane highways. These lanes quickly reach their capacity and must be upgraded on a regular basis. To do so, we must first determine the capacity of the street. The primary objective of this study was to determine the effect of carriageway width, the radius of the horizontal curve, and gradients on Passenger Car Unit (PCU) values as well as on capacity of two-lane undivided Highways, and more importantly, to develop a multiple linear regression model to determine the capacity of the highway when all of these factors are present, which has not been previously reported. Green shield's model was used to estimate the capacity of each element for all thirty-six sections using flow and speed data. Different models were built using regression analysis to estimate capacity independently, and the combined model was developed as a result. It has been noted that with proportionate increases in carriageway width and radius of the curve, there is an equivalent rise in PCU values and highway capacity, providing improved comfort and safety to road users. It was also discovered that when the value of the gradient increases cause increase in PCU values but the highway capacity decreases, thereby increasing the vehicle operating cost. Where all of these characteristics are present simultaneously in a section, the resulting multiple linear regression model was proven to be appropriate. It is believed to be valuable to practitioners as well as in the development or revision of Indian highway capacity manuals.

Keywords:

Carriageway width;
Horizontal curve;
Passenger car unit;
Highway capacity;
Multiple linear equations.

1 Introduction

Many developing countries are still struggle with better traffic flow and smooth vehicular operations because predominant highways are two-lane, two-way mixed traffic with lesser lane discipline.

Study in heterogeneous traffic conditions is a bit challenging for the researchers because of the interference of slow moving traffic under varying static and dynamic characteristics with the fast moving vehicles. The study of traffic speed characteristics is an important requirement in the geometric design of roads, accident analysis, implementation of control devices, and determination of dynamic PCU values for assessing the level of service and capacity estimation of the roadway.

The estimation of highway capacity is an important phase in the planning, design, and operation of highways [1]. It is a very useful tool for evaluating expenditures and determining whether or not further expansion or other future improvement is required. Aside from other elements such as the composition of the traffic stream, directional split, pedestrian interference, driver behaviors, rains, snows, and so on, geometric aspects such as the horizontal and vertical alignment of roadways are even more essential. The assessment of capacity under mixed traffic scenarios at various road geometries is a difficult task [2]. Examining the relationship between different geometric components and roadway capacity is extremely important since it aids in the planning and design phases of various roadway facilities throughout the planning and design stage. The goal of this study is to determine the

impact of changes in carriageway width, radius of horizontal curve, and percentage of gradients on PCU and two lane highway capacity, as well as to create a multiple linear regression model (combined model) to estimate the capacity when all the geometrics were present at a particular section [3]. National cooperative Highway Research Program-NCHRP [4] addressed several issues related to highway capacity estimation for developed countries, hence it motivates the researcher to establish suitable capacity estimation model [5] under different road geometrics in plain terrain and rolling terrain for developing Indian roads.

2 Literature review

It's critical to understand and evaluate the approaches used by different researchers to attain their objectives and, as a result, uncover the gaps in their study. The current state of inter-urban highway capacity studies in India were discussed, covering single-lane, intermediate-lane, two-lane, multilane, and expressways. The article gives a broad overview of capacity-related work over the previous four decades and examines the challenges researchers had in producing the highway capacity manual for Indian contexts, notably owing to the mixed character of traffic and non-lane based vehicle movement [6]. Demonstrated effort of different researchers in developing the PCU values by various techniques and concluded that, Chandra's method is the only method that can be applied to the Indian condition for mixed traffic characterized by loose lane discipline [7]. A research attempted to calculate highway capacity by analyzing traffic flow in terms of PCU and speed of traffic stream at various times of day. Volume and speed were used to establish the speed-flow equation. According to their investigation, the polynomial shape of curve was most suited for the study region, and the capacity achieved was determined to be substantially lower than the IRC requirements [8]. Horizontal alignment features are the most important parameters influencing road capacity and safety among the many types of highway geometry. By studying at six two-lane, two-way roads in Egypt, attempted to quantify the capacity loss between the tangent (straight segment) and the curved portion. To calculate the capacity, a flow-density diagram was employed, and regression analysis was used to create several models. The findings revealed that as the lane width increased, so did the capacity, although the radius of the horizontal curve increased, the capacity increased for the curved area. With the increased radius and width of the curved parts, the capacity loss was minimal. There was no capacity reduction recorded when the radius was greater than 900 m [9].

Two researchers did research on how cars move at nine points where they cross tangents or curves. The results indicated that the horizontal alignment parameters, particularly the curve radius value, had a substantial influence on the follower 5density. By reducing the radius, the density of followers increased (vehicle operating performance decreased). Also, they were found that the value of the horizontal curve radius that fell between 400 and 450 m seemed to be the point where curve radius had a big impact on traffic performance [10].

The effect of gradient on vehicle movement is significant since it influences speed, PCU, and capacity. This is especially important on roads where there are a lot of heavy vehicles. Because the current study focuses on two-lane undivided national roads with mixed traffic flow, it is extremely important to analyze the amount of grade and its impact on highway planning and design. Many research has been undertaken to examine the impact of grades. According to one of the research, vehicles' performance is affected by gradient and its length [11]. Chandra, gathered data on two-lane highways around the country. He discovered that every 1 % upgrade reduces capacity by 2.61 %, whereas every 1 % downgrade increases capacity by 3.09 % [12]. An appropriate method for predicting traffic characteristics (dependent variables) on a specified region for two or more independent factors is linear regression. In order to assess traffic flow using a multiple linear regression technique he proposed combining five topographical variables (degree, betweenness, proximity, page rank, and clustering coefficient) and the length of the road. The equation available has also been shown to be beneficial for transport planners in estimating traffic flow [13]. The authors were identified the limitations and gaps in the speed-flow relationship, appropriate service measures, treatment of large trucks, guidance on base free flow speed estimation, accuracy of passing lane adjustments. Finally they developed two micro simulation tools SwashSim and TransModeler that are capable of accurately modelling two-lane highways [4]. Qu focused on constructing a multiple regression equation to assess the impact of radius of curvature, steering angle, and coefficient of road friction on the driving speed of a vehicle at the curve. Speed of the vehicle, radius of curve, steering angle, and coefficient of road friction are all taken into account in the formula $Y = 0.163 X_1 - 0.188 X_2 - 17.133 X_3 + 81.546$. Where Y is running speed of vehicle, X_1 = radius of curvature, X_2 = steering angle

and X_3 = co-efficient of road friction [14]. Analyzing variance (ANOVA) is a useful technique for determining the optimum strategy for completing a certain project using the results; it is possible to assess a method's viability and efficiency. Various authors built and validated models for various traffic flow characteristics using SPSS software [15-17]. Identified and confirmed the link between dependent and independent variables in this study [18]. ANOVA can be used to check the feasibility and effectiveness of the method used.

3 Objectives of the study

The main objectives of this study are:

- 1) To study the effect of roadway geometrics such as carriageway width, the radius of horizontal curve, and extent of gradient on PCU values and to develop the new dynamic PCU values under heterogeneous traffic conditions on different sections of national highways.
- 2) Estimate capacity using a linear regression equation and verify it against the real traffic flow taking into account factors such as road geometry and comparing their effects on the speed-volume relationship at various points along the route.
- 3) To use SPSS software to create a linear and multiple linear regression model in the form of an equation to estimate the capacity (dependent variable) of a two-lane undivided highway under different road geometries such as carriageway width, curve radius, and gradient (Independent variables).

4 Description of study sites

Thirty-six number sections were identified on three different two-lane undivided Indian national highways (NH) where the effect of carriageway width, horizontal curve radius and gradient were to be assessed. These locations are narrated as below in Table 1.

Table 1: Detail of study area's.

NH	Total length [km]	Major junctions		Locations	Renamed NH
		from	to		
206	650	Chittor	Honnavar	Chintamani, Gouribidanur, Sira, Banavara, Shivamogga, Sagara, Jogfalls.	69
207	143	Dobbaspeta	Hosur	Doddaballapur, Devanahalli, Sarjapura, Bagalur.	648
209	323	Bengaluru	Coimbatore	Kanakapura, Sathanur, Malavalli, Kollegala, Chamarajanagara, Sathyamangalam, Puliampatti, Annur, Kavilpalayam.	948

A reconnaissance survey was carried out to gather fundamental information on the road's condition as well as information about its number of lanes, width of the lanes, and impediments causing the delay. Traffic studies were carried out manually to gather information on the various types of vehicles and their speeds at various sections of the roadways from 7am to 7pm for period of seven days in order to build the speed-volume relationships as shown in Fig.1.



Fig. 1: Traffic volume count by manual method on two lane national highways.

For the purpose of measuring speed, a longitudinal trap with a length of 30 m was placed on each segment and two reference lines were placed on each trap.

The time is started when front wheel of the vehicle crosses the first reference line and stopped when front wheel of the same vehicle crosses the second reference point. The time to clear the trap length is noted and speed is calculated by using the formula (1).

$$Spot\ Speed = \frac{Distance}{Time\ taken} \tag{1}$$

In order not to distract the behavior of driver, manual recording was done by an observer standing at the road side.

5 Analysis of data and discussions

5.1 Average traffic composition

The composition of vehicles in traffic stream is an essential criterion for geometric design as well as structural design of any road. Interpretation of traffic proportions gives a sense about different composition of vehicles. Vehicle class percentage on different two lane highways considered as study areas are shown in Fig. 2 to 4. It is found that two wheelers and cars occupied major portion of traffic in all the sections of different national highways.

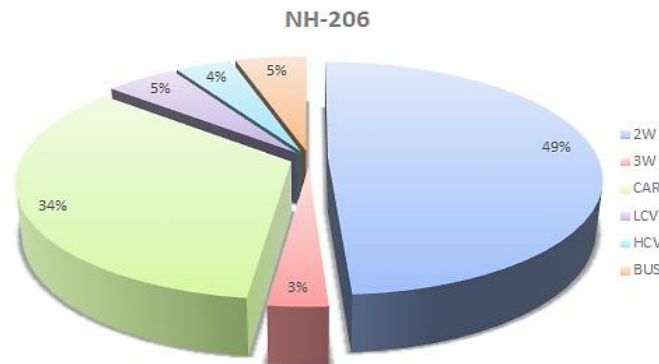


Fig. 2: Observed traffic composition on NH-206.

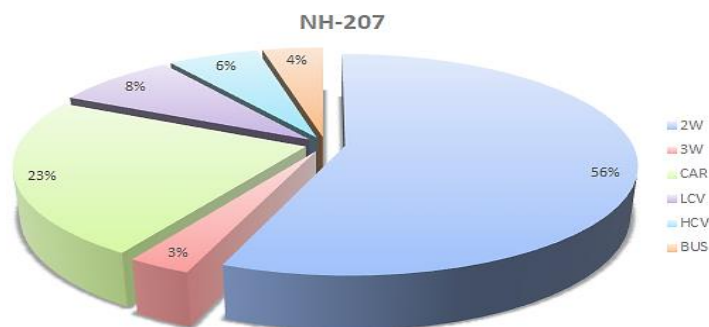


Fig. 3: Observed traffic composition on NH-207.

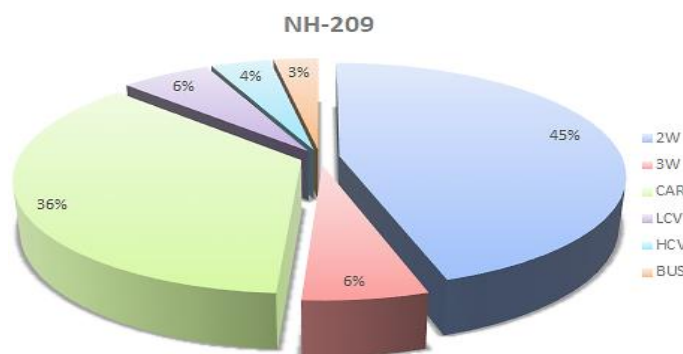


Fig. 4: Observed traffic composition on NH-209.

5.2 Determination of passenger car unit

The major difficulty in developing speed-flow relationship is heterogeneous traffic condition. The mixed vehicles produce different degree of interference due to their different static, dynamic and driver characteristics. For this reason, it is essential to bring all type of vehicles to a common unit by using some certain conversion factors. Many researchers have developed different techniques to find PCU value for different class of vehicles. However Chandra’s method is the only method that can be applied to Indian mixed traffic flow characterized by less lane discipline hence, adopted in the present study [19].

In the current study on two lane highways, the method used to estimate the PCU is that, it is directly proportional to the ratio of space mean speed and inversely proportional to the projected rectangular area of vehicle.

$$PCU = \frac{\text{speed ratio of car to the } i\text{th vehicle}}{\text{space occupancy ratio of car to the } i\text{th vehicle}} \quad (2)$$

5.2.1 Effect of carriageway width

The intention behind this study is to determine PCU values with varying carriageway width and also showing the variation in PCU values for different category of vehicles with the change in speed and its static dimensions. These values were used to express traffic volume in homogenous condition, there by speed-volume relationships were plotted to estimate capacity. Fig. 5 and 6 show variation in PCU values calculated by using the equation (2) for different type of vehicles with varying carriageway width at different sites.

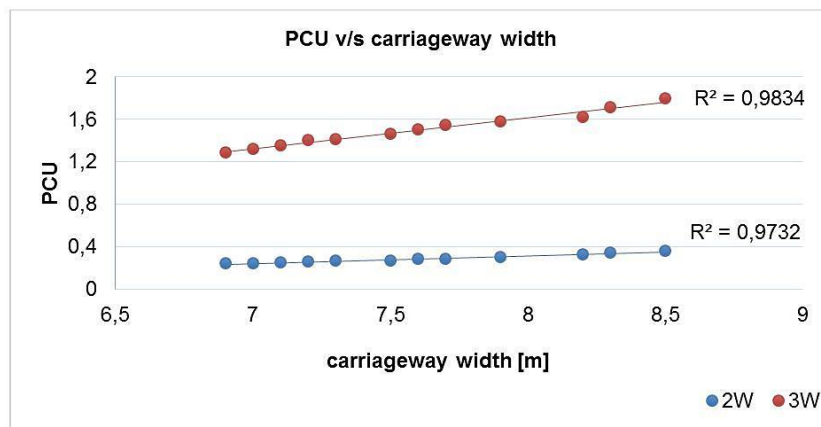


Fig. 5: Effect of carriageway width on PCU for 2 wheeler and 3 wheeler.

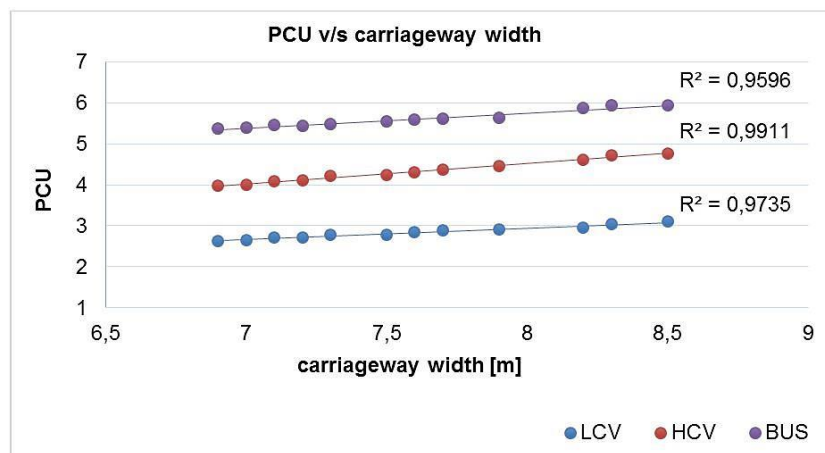


Fig. 6: Effect of carriageway width on PCU for large vehicles.

It is observed that, the PCU for different category of vehicles increasing linearly with the increase in carriageway width. The explanation for this relationship is that as the carriageway width increases it tends the driver’s to go with greater speed. According to equation (2), PCU values are

directly proportional to speed ratio, thus PCU also increases. Also PCU values of 2W and 3W wheelers with the change in carriageway width is slightly varied or constant as compared to buses and heavy commercial vehicles, since speed remains unchanged or little changed in small motorized vehicles.

5.2.2 Effect of radius at horizontal curve

Fig. 7 and 8 show variation in PCU values calculated by using the equation (2) for different category of vehicles with varying radius of horizontal curves at different sites.

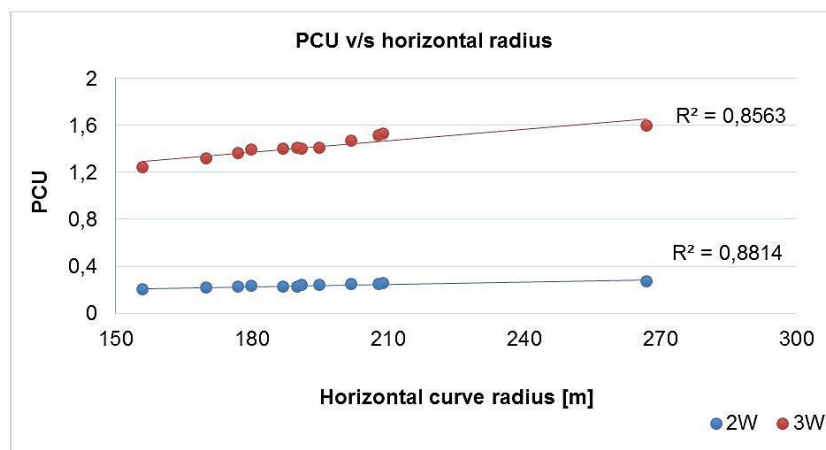


Fig. 7: Effect of horizontal curves radius on PCU for 2 wheeler and 3 wheeler.

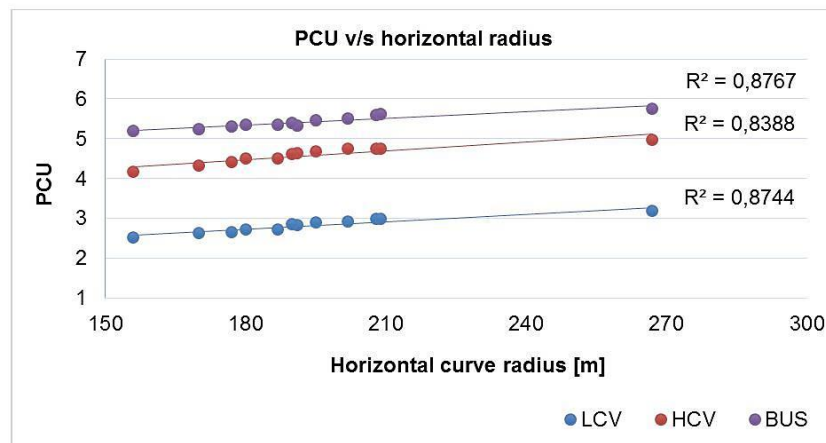


Fig. 8: Effect of horizontal curves radius on PCU for large vehicles.

The PCU for different vehicles increasing linearly with the increase in radius of horizontal curves. The explanation for this relationship is that as the radius of curve increases it tends the driver's to go with higher speed. According to equation (2), PCU values are directly proportional to speed ratio, thus PCU also increases. Also observed that slow moving vehicles such as HCV and Buses are greatly influenced by varying radius because of larger variation in speed as compared to small motorized vehicles.

5.2.3 Effect of gradient

Fig. 9 and 10 show variation in PCU values calculated by using the equation (2) for different category of vehicles with change in percentage of gradients at different sites.

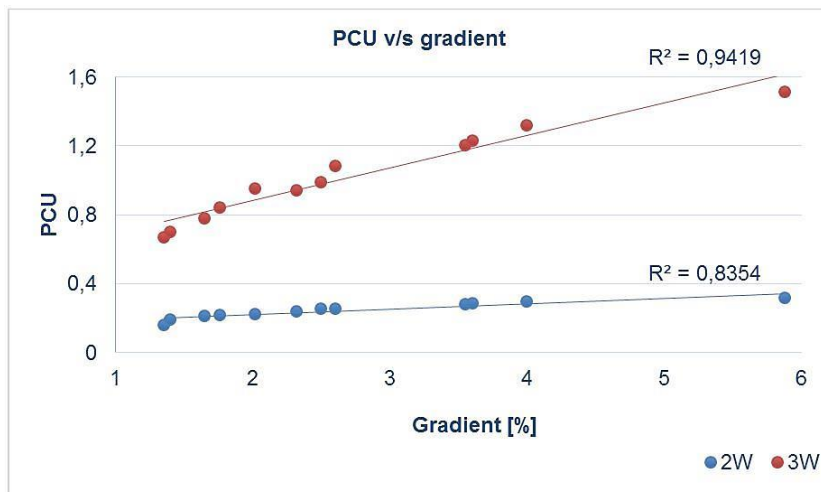


Fig. 9: Effect of gradients on PCU for 2 wheeler and 3 wheeler.

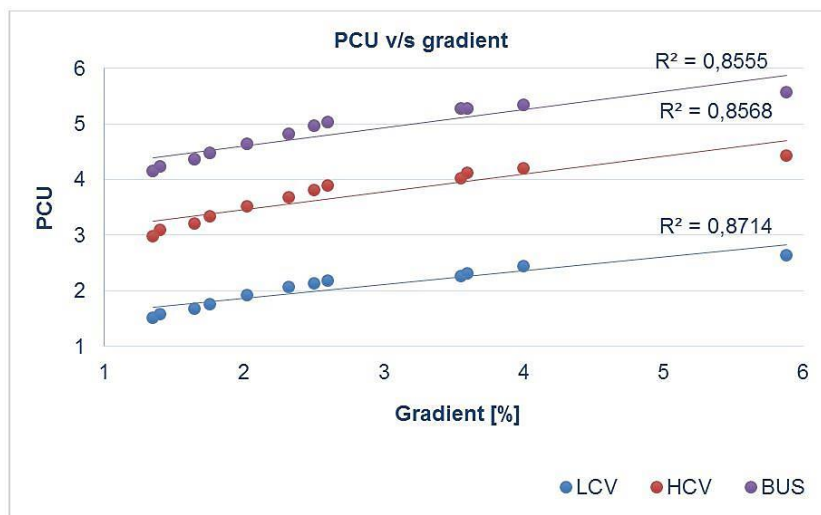


Fig. 10: Effect of gradients on PCU for large vehicles.

It is found that, the PCU for classified category of vehicles increasing linearly with the increase in percentage of gradient, because of slower vehicles and greater occupying of area. Also observed that slow moving vehicles are greatly influenced by change in grade as compared to small motorized vehicles.

5.3 Capacity estimation of two lane national highways

As previously stated, no extensive research has been conducted on the combined influence of the three major factors, carriageway width, horizontal curve radius, and gradient. Taking all of this into consideration, a study has been undertaken to build a systematic approach for determining the capacity of two-lane highways under various roadway layouts utilizing a speed-volume relationship, and thereby constructing a mathematical model.

5.3.1 Carriageway width

It was aimed to develop a regression model to estimate the capacity of two-lane undivided highways with a change in carriageway width. The graphical representation of the speed-volume relationship to estimate the optimum value of capacity with varying carriageway widths under prevailing conditions of highways is shown in Fig.11.

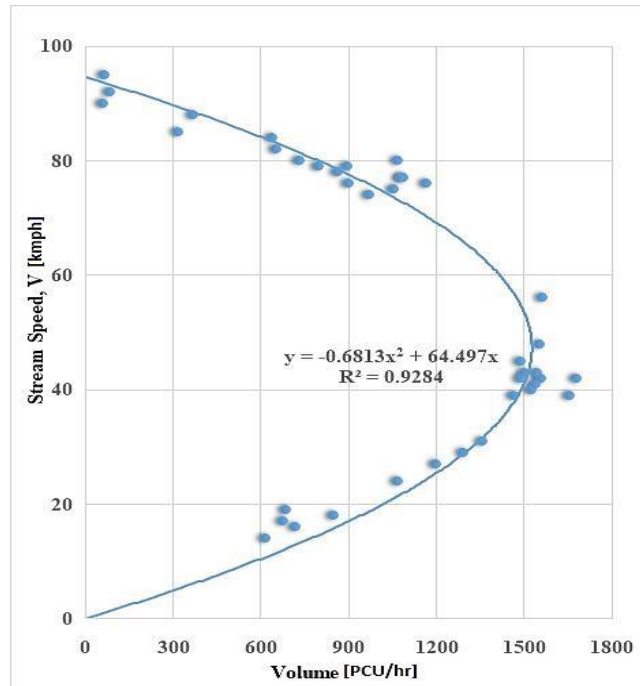


Fig. 11: Speed-volume relationship with varying carriageway width (Site No. 01- NH 206).

Similarly, the mean stream speed at which the maximum flow/capacity value occurs on a particular section of the highway with change in carriageway width was drawn for other sections also, and the values are tabulated in Table 2 [19].

Table 2: Two-lane highway observed capacity under varying carriageway widths.

Site No.	Carriageway width [m]	Capacity as per speed-volume relationship [pcu/hr]	Mean stream speed [km/h]
1	7.9	1526	47
2	7.2	1395	42
3	7.5	1465	45
4	8.2	1553	48
5	7.1	1387	42
6	7.0	1375	41
7	8.5	1698	51
8	8.3	1666	50
9	7.7	1517	47
10	7.3	1414	43
11	7.6	1506	46
12	6.9	1361	40

It is observed that capacity values ranged between 1361 and 1698 PCU/hr. while comparing the capacity values, we found that it is consistent with the range of capacity values reported in HCM-2010 (1600PCU/hr/lane for plain terrain) [20]. After determining the capacity (Table 2) from speed-volume relationships, a model was developed by using the SPSS software [22]. The summary of the model and the analysis of variance obtained from the SPSS are tabulated in Table 3 and Table 4.

Table 3: Summary of the model with a varying carriageway width.

Model	Multiple R	R ²	Adjusted R ²	Std. error
1	0.959 ^a	0.920	0.906	29.775

a) Predicting variable (constant): carriageway width

From Table 3, it is found that the multi correlation coefficient of dependent and independent variables is 0.959 and regression co-efficient R^2 is 0.920. The adjusted R^2 is found to be 0.906, which is very high. Hence, the derived equation is validated.

Table 4: Analysis of variance with varying carriageway width.

Model	Df	Sum of square SS	Mean of square MS	F	Significance F
Regression	1	61314.45186	61314.45186	69.15751137	0.000163997
Residual	6	5319.548143	886.5913571		
Total	7	66634			

Model	Coefficients	Std. error
Intercept	18.48218347	176.840828
Carriageway width	192.8430629	23.18912397

As seen from the ANOVA in Table 4, significance level sig = 0.000163997 < 0.05 means that the lane width affects capacity significantly. It also shows that it is a stronger regression model. The coefficients for carriageway width and intercept were obtained and the linear regression model was established as shown in equation (3).

$$C = 192.84X + 18.482, \tag{3}$$

where C = capacity of highway (pcu/hr) and X = width of carriageway, min. 6.9 m.

5.3.2 Radius of horizontal curve

To study the individual effects of horizontal curve radius on highway capacity [21], a total of twelve sites were selected on three different national highways. The graphical representation of the speed-volume relationship to estimate the optimum value of capacity with varying horizontal curves radius under prevailing conditions of highways is shown in Fig.12.

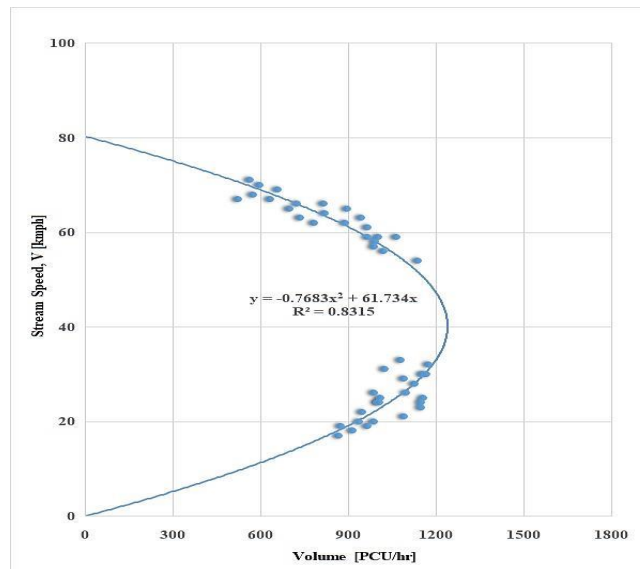


Fig. 12: Speed-volume relationship with varying radius of horizontal curves (Site No.1-NH209).

Similarly, the mean stream speed at which the maximum flow/capacity value occurs on a particular section of highway with change in radius of horizontal curves were drawn for the other sections also and the values are tabulated in Table 5.

Table 5: Two-lane highway capacity under the change in radius of horizontal curves.

Site No.	Curve radius [m]	Capacity as per speed-volume relationship [pcu/hr]	Mean stream speed [km/h]
1	177	1240	40
2	209	1512	49
3	208	1490	48
4	156	1076	36
5	180	1302	42
6	187	1323	42
7	170	1206	40
8	267	1608	53
9	191	1401	44
10	190	1395	45
11	195	1432	46
12	202	1467	47

By substituting the collected samples in the software and running the coefficients that establish the relationship between dependent variables such as capacity, the independent variable - radius of horizontal curves was obtained. The summary of the model and analysis of variance obtained from the SPSS are tabulated in Tables 6 and 7.

Table 6: Summary of the model with varying radius of horizontal curves.

Model	Multiple R	R ²	Adjusted R ²	Std. error
1	0.897 ^a	0.805	0.772	82.374

a) Predicting variable (constant): Radius of horizontal curve.

From Table 6, it is found that multi correlation co-efficient of dependent and independent variable is 0.897 and regression co-efficient R^2 is 0.805. The adjusted R^2 is found to be 0.772, which is high. Hence, the derived equation is validated.

Table 7: Analysis of variance with varying radius of horizontal curves.

Model	Df	Sum of square SS	Mean of square MS	F	Significance F
Regression	1	168022.5668	168022.5668	24.7617389	0.002511451
Residual	6	40713.4332	6785.572201		
Total	7	208736			

Model	Coefficients	Std. error
Intercept	464.8557378	185.3059388
Radius of curve	4.64022554	0.932499313

As seen from the ANOVA in Table 7, significance level $\text{sig} = 0.002511451 < 0.05$ means that the radius of horizontal curve affects capacity significantly and also shows it is a stronger regression model. The coefficients for the radius of horizontal curve and intercept were obtained and the linear regression model was established, as shown in equation (4).

$$C = 4.6402X + 464.86, \quad (4)$$

where C = capacity of highway (pcu/hr) and X = radius of curve, min 156 m.

5.3.3 Gradient

To study the individual effect of gradient on highway capacity, a total of twelve sites were selected on two different national highways. The graphical representation of the speed-volume relationship to estimate the optimum value of capacity with different gradients under prevailing conditions of highways is shown in Fig. 13.

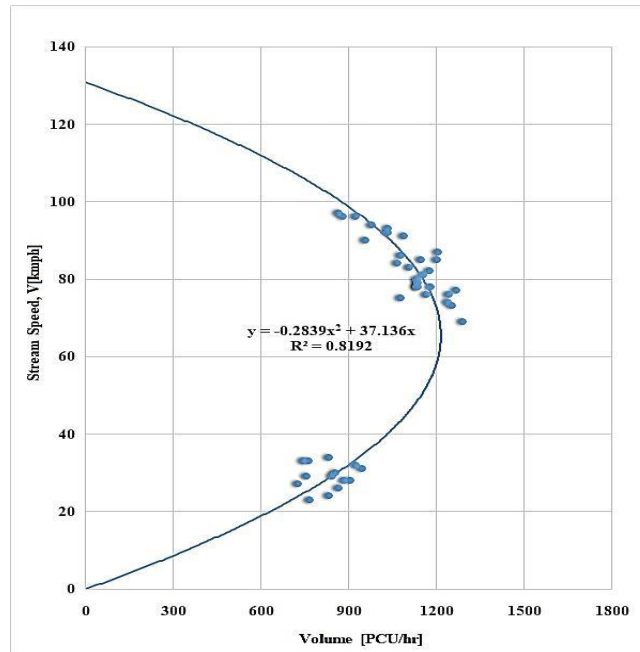


Fig. 13: Speed-volume relationship with varying gradient (Site No.1-NH209).

Similarly, the mean stream speeds at which the maximum flow/capacity value occurs on a particular section of highway with change in gradient were drawn for the other sections also, and the values are tabulated as given in Table 8.

Table 8: Two-lane highway capacity under the change in gradients.

Site No.	Gradient [%]	Capacity as per speed-volume relationship [pcu/hr]	Mean stream speed [km/h]
1	1.35	1214	65
2	1.65	1197	60
3	1.4	1204	62
4	1.76	1153	59
5	2.5	1045	55
6	2.6	1033	55
7	2.32	1086	57
8	2.02	1131	58
9	5.88	872	36
10	3.55	1008	54
11	3.6	995	52
12	4.0	943	49

It is observed that capacity values ranged between 872 and 1214 PCU/hr. while comparing the capacity values from other developing country, we found that it is consistent to the range of capacity values reported by Indonesia-HCM-1995 (1500PCU/hr/lane for flat terrain and 1550PCU/hr/lane for rolling terrain) [22]. As a part of this study, linear regression analysis (second-degree relationship) has been done by substituting the observed capacity from an individual section. Summary of the model and analysis of variance obtained from the SPSS are tabulated in Tables 9 and 10.

Table 9: Summary of the model with varying gradient.

Model	Multiple R	R ²	Adjusted R ²	Std. error
1	0.9550 ^a	0.9121	0.8974	37.3386

a) Predicting variable (constant): Gradient.

From Table 9, it is found that the multi correlation coefficient of dependent and independent variables is 0.9550 and regression co-efficient R^2 is 0.9121. The adjusted R^2 is found to be 0.8974, which is very high. Therefore, the equation derived is validated.

Table 10: Analysis of variance with varying gradient.

Model	Df	Sum of square SS	Mean of square MS	F	Significance F
Regression	1	86813.84461	86813.84461	62.26911839	0.000219529
Residual	6	8365.03039	1394.171732		
Total	7	95178.875			

Model		Coefficients	Std. error
Intercept		1276.467411	28.08279335
Gradient		-74.12313074	9.393282761

As seen from the ANOVA in Table 10, significance level sig = 0.000219529 < 0.05 means that gradient affects capacity significantly. It also shows that it is a stronger regression model. The coefficients for gradient and intercept were obtained and the linear regression model was established as shown in equation (5).

$$C = -74.123X + 1276.5, \tag{5}$$

where C = capacity of highway (pcu/hr) and X = gradient, min 1.35 %.

5.4 Stepwise multiple regression model approach

In this approach, a stepwise regression model has been developed to demonstrate the relationship between dependent variables (capacity) and the independent variables (carriageway width, radius of the horizontal curve, and the gradient). The data's used are given below in the Table 11. SPSS software has been used to develop the co-efficient of different variables X_1, X_2, X_3 to determine dependent variable Y thereby multiple linear regression equation has been established.

Table 11: Observed dataset using in the development of combined equation.

Sl. No	Particulars 1		Particulars 2			Particulars 3		
	C/W width [m]	Capacity	Radius of curve [m]	C/W width [m]	Capacity	Gradient [%]	C/W width [m]	Capacity
1	7.9	1526	209	7.5	1512	1.35	7.5	1214
2	7.5	1465	156	7.2	1076	1.4	7.5	1204
3	8.2	1553	180	7.2	1302	1.76	7.4	1153
4	7.1	1387	170	7.2	1206	2.5	7.4	1045
5	7.0	1375	267	7.6	1608	2.6	7.4	1033
6	8.3	1666	191	7.2	1401	2.02	7.4	1131
7	7.3	1414	195	7.3	1432	5.88	7.2	872
8	7.6	1506	202	7.3	1467	3.6	7.3	995

The introduction order of all the independent variables considered in the present study to the equation is carriageway width, horizontal curve radius, gradient respectively and the result of obtained model is given below in Table 12.

Table 12: Summary of the model

Model	Multiple R	R^2	Adjusted R^2	Std. Error
1	0.8957 ^a	0.8023	0.7727	103.004

a) Predicting variable (constant): X_1, X_2, X_3 .

X_1 = carriageway width, X_2 = radius of horizontal curve, X_3 = gradient.

From Table 12, it is found that multi correlation co-efficient of dependent and independent variables are 0.8957 and regression co-efficient R^2 is 0.8023. The adjusted R^2 is found to be 0.7727, which is high. This means the derived equation will explain the 77 % change in the capacity that occurred due to the change in variables; therefore, the equation derived is validated.

Table 13: Analysis of variance.

Model	Df	Sum of square SS	Mean of square MS	F	Significance F
Regression	3	861437.034	287145.7	27.0642	3.05E-07
Residual	20	212195.925	10609.8		
Total	23	1073632.958			

Model	Coefficients	Std. error
Intercept	-717.448	562.899
Carriageway width	283.173	74.137
Radius of curve	0.196	0.261
Gradient	-99.113	16.392

As seen from the ANOVA in Table 13, significance level sig = 3.05E-07 < 0.05 means that the gradient affects capacity significantly. It also shows that it is a stronger regression model. The coefficients for carriageway width, the radius of the horizontal curve, gradient and intercept were obtained and established the multi-linear regression model, as shown in Equation (6).

Capacity = 283.173* carriageway width + 0.196*radius of curve – 99.113*gradient – 717.45
(6)

5.5 Validation of model

The model goodness of fit has been checked in every step of regression analysis to assess how each variable affects the capacity of the highway. Further, a set of observed capacity for different carriageway widths, the radius of the horizontal curves and gradients have been compared with the estimated capacity obtained from the multiple linear regression equation in the form of mean absolute percentage error, as shown in Table 14.

Table 14: The MAPE values for the multi linear regression model.

Carriageway width [m]	The radius of curve [m]	Gradient [%]	Observed capacity for			Estimated capacity as per		MAPE [%]
			Carriageway width [m]	The radius of curve [m]	Gradient [%]	Linear regression analysis	Multiple linear regression analysis	
7.2	-	-	1395	-	-	1411.4	1321.4	5.3
8.5	-	-	1698	-	-	1693.5	1689.5	0.5
6.9	-	-	1361	-	-	1346.3	1236.4	9.1
7.7	-	-	1517	-	-	1519.9	1463	3.5
7.1	177	-	-	1240	-	1254.0	1327.7	7.1
7.4	208	-	-	1490	-	1502.0	1418.8	4.8
7.3	187	-	-	1323	-	1334.0	1386.4	4.8
7.2	190	-	-	1395	-	1358.0	1358.6	2.6
7.3	-	3.55	-	-	1008	992.3	997.8	1.0
7.2	-	1.65	-	-	1197	1180.1	1157.8	3.3
7.1	-	4.0	-	-	943	947.8	896.5	4.9
7.1	-	2.32	-	-	1086	1113.8	1063.1	2.1
MAPE								4.1

6 Discussions

Traffic surveys on different two lane national highways were carried out and determined the percentage composition of vehicles as well as free speed at different sites along the stretches. It is

found that two wheelers occupies major portion (50 %) of the traffic followed by car (31 %) in the mixed traffic condition. PCU values were determined by using Satish Chandra's method. It has been observed that PCU for different vehicles increasing linearly with the increase in lane width, radius of horizontal curve and gradient. Also noticed that incase of light vehicles the PCU have slight variation or constant as compared to heavy vehicles. Later by using speed-volume relationships capacity has been observed (actual capacity). Attempt has been made to establish the linear relationships between observed capacity and other variables in the form of linear equations obtained by using SPSS software thereby estimated capacity for different variables such as lane width, radius of curve and gradient. Obtained high regression coefficients with a marginal mean absolute percentage error (MAPE), hence the equations obtained are highly validated. It is observed that there is an equivalent increase in capacity with the proportionate increase in lane width and radius of curve, consequently it provides more comfortness and safety to the road users. It is also observed that the outcome of increased amount of gradient causes reduction in capacity and increases the vehicle operation cost. Finally multiple linear regression analysis is carried out by using SPSS software to develop regression equation with capacity as dependent variable and lane width, horizontal curve radius and gradient as independent variables. To validate the same comparison has been made between observed and estimated capacity. The MAPE obtained is 4.1 percent which is very marginal, hence the equation obtained is persuasive and more applicable.

7 Conclusions

The specific conclusions that can be drawn from the current research are listed below.

1) Dynamic PCU values at different sites for classified category of vehicles were found using Satish Chandra's method. This study reflects the effect of three predominant variables such as carriageway width, radius of horizontal curve, and gradient on PCU values and thereby on capacity of two lane highways. It is found that PCU of different vehicles increases linearly with the increase in lane width, radius of curve and gradient.

2) It has been observed that incase of light vehicles (2W, 3W, Car) the dynamic PCU values slightly vary or remain constant with the increase in carriageway width, radius of curve and gradient as compared to heavy vehicles (Bus & HCV).

3) Capacity obtained from green shield's model of speed-flow diagram for carriageway width is found to be in the range of 1361 to 1698 *PCU/hr/lane*, for radius of horizontal curve is in the range of 1076 to 1608 *PCU/hr/lane*, and for gradient is in the range of 872 to 1214 *PCU/hr/lane*. Capacity values obtained are found to be more consistent with capacity values given in HCM-2010 (1600*PCU/hr/lane* for flat terrain) and Indonesia-HCM (1500*PCU/hr/lane* for flat terrain and 1550 *PCU/hr/lane* for rolling terrain).

4) Capacity of a two-lane highway was determined by developing linear regression equations individually based on carriageway width, the radius of the horizontal curve and gradient by using SPSS software with higher regression coefficients R^2 . The regression equations are as follows.

5) Capacity (carriageway width) = $192.84 \times \text{lane width} + 18.482$ $R^2 = 0.9202$.

6) Capacity (radius of horizontal curve) = $4.6402 \times \text{radius} + 464.86$ $R^2 = 0.805$.

7) Capacity (gradient) = $-74.123 \times \text{gradient} + 1276.5$ $R^2 = 0.9121$.

8) From the above relationships, it is observed that there is an equivalent increase in highway capacity with the proportionate increase in carriageway width and radius of curve. Consequently, it provides more comfort and safety to the road users. Also, it is noticed that the outcome of an increased amount of gradient causes a reduction in highway capacity and increases the vehicle operating cost.

9) By considering capacity as a dependent variable and carriageway width, the radius of the horizontal curve and gradient as independent variables, a multiple linear regression analysis has been carried out using SPSS software with higher regression coefficients. The regression equation is:

10) Capacity = $283.173 \times \text{carriageway width} + 0.196 \times \text{radius of curve} - 99.113 \times \text{gradient} - 717.45$

11) Using the above equation, the capacity has been estimated. To validate the results between observed and estimated capacity, mean absolute percentage error (MAPE) was computed. It has been observed that the mean error is 4.1 percent between observed and estimated capacity. This substantiates the analysis and the developed model can be utilized for other applications in traffic engineering.

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