

Capacity Analysis of a 4-Lane Intercity Road with varying Shoulders

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ABSTRACT

Speed-flow relationships and capacity analysis of a 4-lane intercity road are brought out in this paper under varying conditions of shoulders of the road. The shoulder conditions considered in the study are surfaced shoulder, good shoulder, average shoulder and poor shoulder. Speed flow study has been conducted on a 4-lane intercity road at various sections of varying shoulder conditions. Passenger car unit equivalence factors are determined for various vehicles for each studied section of the road which are used to get the traffic flow in pcu/hr. Speed-flow relationships have been developed which are further used for estimation of capacity of the road. Poor condition of the shoulder has been found to reduce the capacity of the road. Adjustment factors for capacity of a 4-lane road with varying conditions of shoulders are also given in the paper.

1. INTRODUCTION

Speed-flow relationships and capacity of a road are the basis for planning, design and operation of roads. These are important tools for evaluation of the investments for future road constructions. They also help in working out priorities between the competing projects. In India, roads play the most important role in the transportation sector as they carry around 70 % of the freight traffic and 85 % of the passenger traffic. The country has over 56-lakh km of road network that is second largest in the world. Intercity roads (non-urban roads or rural highways) are the major component of the network and constitute about 80 % of the total road length. Traffic on the roads is increasing at a rate of 7-10 % whereas vehicle population is growing at a rate of about 12 % per annum in the country. Speed-flow relationships and capacity analysis are important for catering to the needs of increased traffic and for optimal utilization of the vast road network in the country.

Literature on traffic flow research on rural highways is mostly available in developed countries where the traffic is homogeneous. The research information is well documented in Highway Capacity Manuals [1],[2],[3],[4],[5] for use of engineers, planners and policy makers. In India the traffic is heterogeneous. The research outcome of developed countries cannot be used without modifications. Traffic studies in the

country related to this topic were mainly conducted in the Road User Cost Study project [6] in which speed-flow relationships were developed for selected rural roads for capacity estimation. Most of the methods for determination of capacity find out capacity of the roads under certain ideal conditions and then reduce the capacity for non-ideal conditions such as substandard lane width and shoulder condition. The same technique has been adopted for the analysis of capacity of roads in the present study also where the capacity is first calculated for certain base conditions and then adjusted for the substandard conditions. Indian Roads Congress (IRC: 64-1990) [7] provides adjustment factors for substandard lane and shoulder width for 2-lane roads only. It has given only the tentative capacity values for the four-lane roads in the absence of sufficient information about the capacity of such roads in the country.

2. METHODOLOGY

The present study aims to estimate the capacity of a 4-lane intercity road with varying conditions of shoulders of the pavement. For this purpose, the speed-flow data were collected on selected stretches of a 4-lane road. The road sections were so selected that the effect of type of shoulder on capacity of the road could be studied properly. In order to study the effect of shoulder on capacity of road, the variation in the shoulder condition is considered to the extent that usually occurs in the field. For better understanding, the shoulders have been divided into different types as per their physical condition. The criteria for this classification are as under:

- (i) Surface Shoulders: These are well-designed paved shoulders provided with bituminous surfacing. The width of shoulder is at least 1.5 m with 1 m earthen surface beyond bituminous surfacing.
- (ii) Good Shoulders: The shoulders are termed as good when difference in level of carriageway and shoulder is less than 25 mm at pavement edge. The shoulders are intact with broken surface less than 25 %. These shoulders are usable at reasonably good speed.
- (iii) Average Shoulders: The difference in level between shoulder and pavement is 25 to 75 mm. Broken surface of the shoulder is 25 to 50 %. Shallow potholes may be present but the shoulder is usable at low speed.

- (iv) Poor Shoulders: The difference in level at pavement edge is more than 75 mm. Broken surface of the shoulder is more than 50 %. It has deep potholes and it is difficult to use the shoulder even at low speed.

The following points were kept in view for selecting sites for this study.

- The site should be a straight levelled stretch. It should be the midblock section, far from the road intersections and the urban traffic.
- The pavement surface should be in good condition.
- There should be no obstruction to the sight distance.
- The pavement, shoulder and road alignment should exhibit uniform conditions for adequate length on both sides of the selected section.
- The placement of the camera / team should be convenient and safe. It should not affect the speed of vehicles.

The speed-flow data were collected using Video Recording Technique (VRT). The speed-flow data were collected on each of the selected sites for about 3 to 4 hours on typical weekdays. These data were supplemented with physical data of the road site such as the width of the carriageway and the shoulders, the condition of the shoulders and the physical dimensions of each vehicle type.

The video recording of the traffic was done using a Video Camera with digital zoom. For recording the traffic, the camera was mounted on the side of the road sufficiently away from the pavement edge (or on the median of the road, as suitable) to cover a trap length of 30 m clearly. The camera was focused at some angle and inclined a little towards the ground to clearly record both the ends of the trap length. The speed-flow data were extracted from the recorded video. A stopwatch of least count 0.01 second was used to note down the time taken by vehicles to travel the trap length. Traffic volume is the number of vehicles that pass a road section per unit time. The rate of flow is the number of vehicles that pass a road section in a time less than 1 hour. Rate of flow is expressed as an equivalent hourly rate. Time intervals of 5 minute to 1-hour have been used to determine capacity of facilities. For determining the highway capacity, a time interval of 5 minute is taken [8]. In a study by CRRI [6], 5-minute count was used to establish speed-flow relationships. Kadiyali et al [9] also used a 5-minute count. They used speed-flow relationships to determine capacity of roads. This time interval of 5 minute helps reduce random variation and also avoids repetitive peaking patterns.

In this study also, a five-minute time interval was used. Equivalent hourly traffic flow rate is obtained using 5-minute count. From the recorded video of the traffic, the speed -volume data was extracted for each five-minute for the total duration of the study. Hourly flow rate is obtained by multiplying the 5-minute traffic count by 12.

It was observed that various types of vehicles were present at different sites selected for this study. To make the analysis of the collected data easier and meaningful, vehicles having similar characteristics were grouped together and all vehicles were divided into 10 categories. Bicycle, cycle-rickshaw, horse-cart and other non-motorized vehicles were put in the category of slow moving vehicles (SMV). Table 1 provides details of categories of vehicles along with their physical dimensions.

The sites for four lane roads were selected to determine the capacity of these roads under varying conditions of shoulders. The sites were so selected that the effect of each shoulder type could be studied individually. The various sites selected for the study are given in Table 2.

3. PCU EVALUATION

The method given by Chandra [10] is used for estimating PCUs for various types of roads with different roadway and traffic conditions. As per this method, the PCU is directly proportional to the speed ratio and inversely proportional to the space ratio.

$$PCU_i = \frac{\text{Speed ratio of the car to the } i^{\text{th}} \text{ vehicle}}{\text{Space ratio of the car to the } i^{\text{th}} \text{ vehicle}}$$

$$PCU_i = \frac{V_c/V_i}{A_c/A_i} \quad (1)$$

Where,

PCU_i = PCU value of i^{th} vehicle

V_c/V_i = speed ratio of the car to the i^{th} vehicle

A_c/A_i = space ratio of the car to the i^{th} vehicle

V_c = average speed of cars over duration of the study (kmph)

V_i = average speed of i^{th} vehicle type (kmph)

A_c = projected rectangular area of car (m^2)

A_i = projected rectangular area of i^{th} vehicle type (m^2)

The speed ratio in Equation (1) is a function of roadway and traffic conditions. Speed ratio explains any change in these conditions as speed of vehicles gets affected by the change. It also represents interaction of a vehicle in the traffic stream with other vehicles of its own category and of other types.

Table 1 Categories of Vehicles

S. No.	Category	Vehicles included	Average Dimensions (m)	Projected Rectangular Area (m ²)
1	Car	Car, Jeep, Van	3.72 x 1.45	5.39
2	Bus	Bus	10.1 x 2.43	24.54
3	Truck	Truck	7.50 x 2.35	17.62
4	LCV	Mini bus, large vans, mini trucks, tractors	6.1 x 2.1	12.81
5	Three Wheelers	Three Wheelers	3.2 x 1.4	4.48
6	Two Wheelers	Scooter, Motorcycle, Mopeds	1.87 x 0.64	1.2
7	Cycles	Pedal Bicycles	1.9 x 0.45	0.86
8	Rickshaw	Pedal Rickshaw, Handcarts	2.7 x 0.95	2.57
9	Tractor-Trailer	Tractor trailer	7.4 x 2.2	16.28
10	ADV (Animal drawn vehicles)	Bullock cart, Horse cart, Tonga	5.0 x 1.7	8.5

Table 2 Sites of Four Lane Road with Varying Conditions of Shoulders (2 x 7.0 m dual carriageway)

S. No.	Road	Study Section Location near	Shoulder Condition
1	Delhi-Ambala (NH-1)	Amin	Surfaced
2	-do-	Taraori	Good
3	-do-	Karnal	Average
4	-do-	Madhuban	Poor

The space ratio in the equation explains the pavement occupancy and depicts ease of movement of a vehicle versus car. The PCU value for each category of vehicle was derived at each test location and used to develop speed-flow relationships.

The PCU values at the selected sections for various types of vehicles are given in Table 3. The shoulder conditions varied from surfaced shoulders to poor shoulders. The variation in shoulder conditions is considered for 2 x 7.0 m carriageway.

Table 3 PCU Values on Four Lane Road with Varying Condition of Shoulders (Dual Carriageway 2 x 7.0 m)

Shoulder Condition	PCU Equivalence for various vehicles								
	Bus	Truck	LCV	Trac. Trl.	3-WH	2-W	Cycle	Rickshaw	ADV
Surfaced	5.40	4.57	3.0	7.26	1.7	0.34	0.71	2.70	10.5
Good	5.36	4.54	2.97	7.1	1.66	0.33	0.68	2.62	9.98
Average	5.30	4.50	2.90	7.02	1.64	0.326	0.64	*	*
Poor	5.26	4.48	2.93	6.98	1.62	0.324	0.66	2.60	9.96

* Vehicles not found during the course of field study

Figure 1 shows the variation in PCU for various types of vehicles with varying conditions of

shoulders on a four-lane road. This variation is shown for a 2x7.0 m wide dual carriageway with good condition of the road pavement and slow moving vehicles less than 8 %. It may be observed from Figure 1 that the PCU value of a vehicle is more for surfaced shoulders and it decreases as the shoulder condition changes from good to poor for all categories of roads under consideration. This may be explained on the basis of speed differential. A good shoulder provides an additional usable width to a vehicle whereas a shoulder in poor condition may even restrict full use of the available carriageway of the road. The vehicles do not come close to the edge of the carriageway especially at higher speeds to offset any danger of running on to the poor shoulder and meeting with an accident. It causes reduction in effective width of the carriageway. Thus a good shoulder can effectively increase the width of the carriageway and, therefore, results in more PCU of a vehicle due to more speed differential between car and a vehicle type.

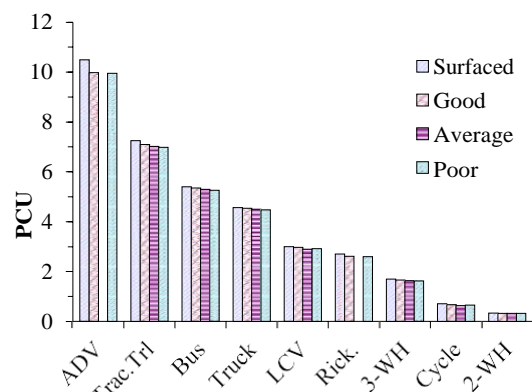


Figure 1 Variation of PCU with Shoulder Condition

4. SPEED-FLOW RELATIONSHIPS

The PCU values estimated in Table 3 for different categories of vehicles at a section were used to convert the flow in terms of PCU/hr. The space mean speeds of vehicles calculated from the observed speed data were used in developing the speed-flow relationships. The space mean speed was calculated as below:

$$V = \frac{3.6 d n}{\sum_{i=1}^n t_i} \quad (2)$$

Where,

V = space mean speed of vehicle type i in five minute count, kmph

d = trap length, m

n = number of vehicles of type i

t_i = observed travel time (sec) for vehicle type i to travel trap length

The mathematical equations relating speed with flow were derived using linear regression analysis for various types of vehicles. These relationships were used to study the effect of shoulder conditions on capacity of the road sections. The speed-flow relationships for the traffic stream for a 2x7.0 m carriageway for varying shoulders are shown in Figure 2. The corresponding speed-flow equations relating speed with traffic volume are given in Table 4.

5. CAPACITY ESTIMATION

The capacity of various sections of the road is derived from their speed-flow relationships drawn for the traffic stream. The idealized speed-flow curve is a parabola where capacity occurs at half the free speed. It is used with the straight-line speed-flow relationship for a section to determine the capacity of road as shown in Figure 3. The intercept of the straight-line on the y-axis gives the free speed. The value of traffic flow with respect to half of free speed gives the capacity of the road. The same technique is used by Kadiyali et al [9] and Indian Roads Congress [7]. The speed-flow relationship for traffic stream for 2x7.0 m wide carriageway for surfaced shoulder as shown in Figure 3 is used to find out capacity of the road as 4500 PCU/hr. As this value is only for one side of the road, the total capacity of the 4-lane road becomes 2x4500 PCU/hr. Similarly the capacity for other sections of the road with varying shoulder conditions was found and the values are given in Table 5 along with adjustment factors.

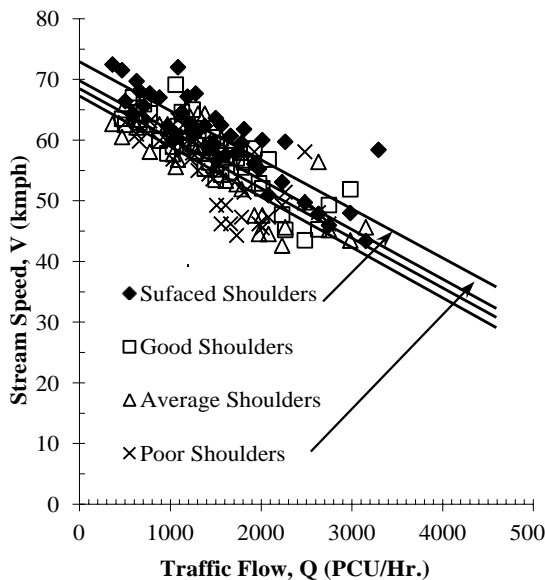


Figure 2 Speed-Flow Relationships on 4-Lane Road with Varying Shoulder Conditions

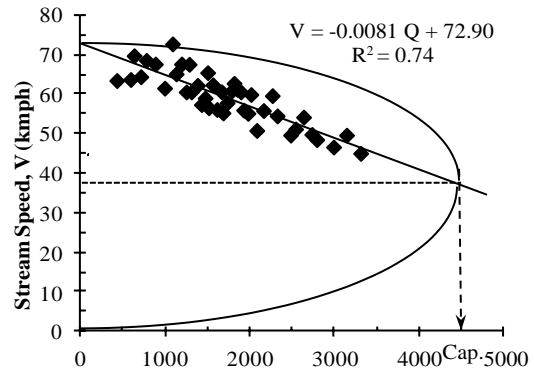


Figure 3 Capacity of 4-Lane Road (carriageway 2x7.0m, surfaced Shoulders)

Table 4 Speed-Flow Relationships for Four Lane Road with Varying Shoulder Conditions (2 x 7.0 m carriageway)

Shoulder Condition	Traffic Stream	
	Relationship	R ²
Surfaced	V = -0.0081 Q + 72.9	0.74
Good	V = -0.0082 Q + 69.770	0.67
Average	V = -0.0082 Q + 68.47	0.67
Poor	V = -0.0083 Q + 67.23	0.57

Table 5 Capacity of 4-Lane Road with Varying Shoulders (2 x 7.0 m carriageway)

Shoulder Condition	Capacity (PCU/hr)	Adjustment Factor
Surfaced	2 x 4500	1.060
Good	2 x 4250	1.000
Average	2 x 4175	0.982
Poor	2 x 4050	0.953

6. EFFECT OF SHOULDER CONDITION ON CAPACITY

It is found that the capacity of the road reduces when the shoulder condition changes from good to poor. This is due to the fact that a road with inferior shoulders has less effective carriageway than a road with good shoulders resulting in a low capacity value. The variation in capacity of four-lane road with shoulder conditions is shown in Figure 4. This plot is for the carriageway of 2x7.0 m and slow moving vehicles less than 8.0 %. It is seen that the capacity of one side of the dual-carriageway 4-lane road decreases from 4500 PCU/hr to 4050 PCU/hr when shoulder conditions change from surfaced to poor shoulders.

7. COMPARISON OF CAPACITY VALUES WITH OTHER NOTABLE WORKS

A comparison of capacity values obtained in the present study with those recommended in Road User Cost Study 1990 (Kadiyali et al 1991) [9], HCM [4], [5], and Indian Roads Congress (IRC-64: 1990) [7] is given in Table 6. These values are for straight sections of the roads in plain terrain and

for good shoulder conditions. It is observed that for four-lane road, a capacity of 8500 PCU/hr in both directions combined obtained in the present study is quite comparable with that given by RUCS 1990 and HCM 1994 and 2000. However, IRC has recommended a much lower value of 5600 - 7000 PCU / hr for a peak hour factor of 8 - 10% respectively. In view of the findings of the present study, IRC recommendations for capacity of 4-lane roads clearly need an upward revision.

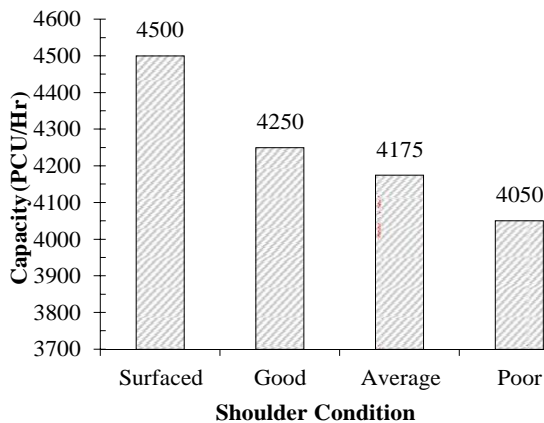


Figure 4 Capacity of a Four Lane Road (one side) with Varying Shoulder Conditions

Table 6 Comparison of Capacity Values with Other Notable Works

Carriage way Width	Capacity (PCU/hr)				
	RUCS (1990)	IRC- 64: 1990 (PHF 8-10%)	HCM (1994)	HCM (2000) ²	Present Study
Four-lane (2x8.5 m)	9300	6400 - 8000	-	-	-
(2x7.3 m)	-	-	8800	8800	-
(2x7.0 m)	-	5600 - 7000	8720	8720	8500

8. CONCLUSIONS

The following main conclusions are drawn from the paper.

1. The PCU for a vehicle is found to be higher at sections of a road where surfaced shoulders are provided. It decreases as the shoulder condition changes from good to poor.
2. Speed-flow relationships have been developed for 4-lane road sections for varying conditions of shoulders.
3. On a given type of road section the free speed of a vehicle reduces and coefficient of Q increases as shoulder conditions change from good to poor.
4. The capacity norms have been developed using speed-flow relationships. It is observed that capacity of the road decreases when shoulder condition changes from good to poor.
5. The capacity of a four lane road under base conditions is 8500 PCU/hr as compared to 8720 PCU/hr recommended in HCM 2000 (TRB,

2000) and 5600-7000 PCU/hr suggested by Indian Roads Congress (IRC: 64-1990) under almost similar conditions. The IRC capacity recommendations clearly need an upward revision in respect of four lane roads.

6. Adjustment factors have been evolved for determining capacity of 4-lane roads under prevailing roadway and traffic conditions. These factors are given for the variation in the shoulder condition. The adjustment factors are multiplicative in nature to be applied to the base capacity to obtain capacity under prevailing conditions of shoulders.

REFERENCES

- [1] Highway Research Board (HRB, 1950), *Highway Capacity Manual*, Bureau of Public Roads, U S Department of Commerce, Washington D.C.
- [2] Highway Research Board (HRB, 1965), *Highway Capacity Manual*, Special report No.87, Washington D.C.
- [3] Transportation Research Board (TRB, 1985), *Highway Capacity Manual*, Special Report 209, Washington D.C.
- [4] Transportation Research Board (TRB, 1994), *Highway Capacity Manual*, Special Report 209, National Research Council, Washington D.C.
- [5] Transportation Research Board (TRB, 2000), *Highway Capacity Manual*, National Research Council, Washington DC.
- [6] Central Road Research Institute (CRRI) (1982), *Road User Cost Study in India*, Final Report, New Delhi.
- [7] Indian Roads Congress (IRC: 64, 1990), *Guidelines for Capacity of Roads in Rural Areas*, New Delhi.
- [8] Papacostas CS (1990), *Fundamentals of Transportation Engineering*, Prentice Hall of India Pvt. Ltd., New Delhi.
- [9] Kadiyali LR, Lal NB, Sathyanarayana M and Swaminathan AK (1991), *Speed - Flow Characteristics on Indian Highways*, IRC Journal. Vol. 52-2, pp 233-262.
- [10] Chandra S (1994), *Development of Capacity Analysis Procedure for Urban Intersection*, Ph.D. Thesis, University of Roorkee, Roorkee.