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CAPACITY ASSESSMENT OF URBAN ROADS UNDER DIVERSE TRAFFIC STIPULATION

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ABSTRACT

In India, condition of traffic due to various kind of vehicles manoeuvring with different lane behaviour and driver behaviour resulting in supremely heterogeneous nature due to their static and dynamic features. Currently the traffic on the road rises rapidly and traffic volume overdoes normal limit. Study of several features of highway traffic is essentially required for preparation, design and manoeuvre of roadway facilities. For the improved vehicular road traffic it needs better roadway structure with greater capacity. An intension of this work is to analyze capacity for urban roads in heterogeneous condition. For the capacity estimation it is relatively tough to estimate traffic volume on the road. The problem of measuring flow may addressed by using Dynamic PCU values. The Capacity of urban roads is find out by green shield model and the results are compared with Microscopic simulation model. The sudden increase in width of lane on the road is checked and result shows that with the increase in road width Capacity of road also increases.

A new concept to estimate the passenger car unit PCU of different types of vehicles under mixed traffic conditions is presented. It utilizes the area, as opposed to only the length, and speed of a vehicle. Data were collected at ten sections of two-lane roads in different parts of India. The width of carriageway this term is commonly used in India for the total width of the paved surface of a road excluding its shoulders ranged from 5.5 to 8.8 m. All vehicles were divided into nine different categories and their PCU's were estimated at each road section. It was found that the PCU for a vehicle type increases linearly with the width of carriageway. This is attributed to the greater freedom of movement on wider roads and therefore a greater speed differential between a car and a vehicle type. The capacity of a two-lane road also increases with total width of the carriageway and the relationship between the two follows a second-degree curve. This relationship is used to derive the adjustment factors for substandard lane widths and the results are compared with literature.

Keywords: *India; Vehicles; Passengers; Data collection; Traffic capacity Traffic Volume, PCU, Traditional model, Simulation model, Traffic Capacity*

I. INTRODUCTION

Two-lane highways compose the predominant portion of most National and State Highway system in the country. Two-third length of National Highways and more than 50 per cent length of State Highways is still two-lane wide. Traffic operation on a two-lane two-way highway is unique. Lane changing and overtaking are possible only in the face of on-coming traffic in the opposing lane. The overtaking demand increases rapidly as traffic volume increases, while passing opportunities in the opposing lane decline as volume increases. Therefore, flow in one direction influences flow in the other direction. The problem is more acute in case of mixed traffic flow when speed differential among different categories of vehicles is quite substantial. It increases the desired number of overtaking considerably with limited opportunities to overtake.

Prediction and knowledge of capacity is fundamental in design, planning, operation and layout of road network sections. Roadway factors that influence capacity of a two-lane road include lane width, gradient, lateral clearance, width and type of shoulder. Lane and shoulder width can have a significant impact on traffic flow. Narrow lanes cause vehicles to travel closer to each other laterally by slowing down or by observing large longitudinal gaps for a given speed. This effectively reduces the capacity. Important traffic conditions that affect capacity of a two-lane road are composition of traffic stream, directional split and presence of slow moving vehicles in the stream.

Environmental conditions such as wet pavement or snow and ice conditions, rain, darkness, fog, parking regulation affect the driver performance and hence capacity. There are indications that wet or icy pavement can reduce capacity by 5-15 per cent25.

II. LITERATURE SURVEY

Taragin and Eckhardt (1953)23 studied the effect of shoulder on speed and lateral placement of motor vehicles and found that when twolane pavements on main highways are 6 m in width or less, shoulders should be constructed with at least 1.2 m of stabilized material, adjacent to pavement plus additional width of grass and gravel. Leong (1978)16 measured speeds and capacity at 31 sites on rural highways in New South Wales. The sites had varying lane and shoulder width and all sites

CAPACITY ESTIMATION PROCEDURE FOR TWO-LANE ROADS UNDER MIXED TRAFFIC CONDITIONS had gravel shoulders. The data were analyzed using multiple regression and it was suggested that speed increased with increasing shoulder width. Prakash (1970)18 also observed that the highway capacity is considerably influenced by the type and width of shoulder. Farouki and Nixon (1976)8 studied the effect of carriageway width on speed of cars in the special case of free-flow conditions in sub-urban roads at Belfast. It was found that the mean free speed of cars in suburban area increases linearly with the carriageway width over a certain range of width (5.2 to 11.3 m). Turner et al. (1982)24 found that the conversion of a shoulder to an additional travel lane could be expected to increase average-speed of a two-lane highway by about 5 per cent for volumes exceeding 150 veh/h. Yagar and Aerde (1983)26 found that speed changes exponentially with change in lane width. Chandra and Kumar (1996)5 studied the effect of shoulder condition on speed of different types of vehicles and their placement on road during passing and overtaking maneuvers on single and two-lane highways. William and Reilly (1992)25 provided a summary of operational techniques that can be used to improve level of service and capacity on two-lane highways. Ramanayya (1988)19 observed that the capacity standards adopted in western countries do not take into account the mixed traffic characteristics prevalent in India. Sarna et al. (1989)21 emphasized on the need of developing highway capacity norms for Indian highways. Kadiyali et al. (1991)13 observed that vehicle speeds on Indian roads have increased during the past ten years. Speed-flow relationships have also undergone changes. Pursula and Enberg (1991) reported from Finland that the highest flow rate measured on two-lane two-way road was 2500 veh/h with a directional split of 50/50. Fi (1994)9 reported that traffic characteristics were similar to HCM and expected traffic volume on two-lane highway was near 1500 pcu/h/l. Bang et al. (1995)1 developed speed-flow relationship and simulation model for twolane road in Indonesia and found that free flow speed for two-lane roads under ideal conditions is considerably lower in Indonesia than in developed countries. Sahoo et al. (1996)20 found that increase in traffic volume decreases the speed of vehicles. Parker (1996)17 observed that knowledge of traffic composition plays an important role in determining capacity. Kumar and Rao (1998)15 observed that speed density data could be reasonably represented by a linear relationship. Hossain and Iqbal (1999)11 studied vehicular free speed characteristics on two-lane national highway of Bangladesh. Karan et al. (1978)14 developed relationship between average speed and pavement conditions for two-lane highways. Schofield (1986) studied effect of light and weather conditions on the speed and capacity of two-lane roads. Brilon and Ponzlet (1997)2 studied influences of environmental factors on the speed-flow relationships on German autobahns.

III. DATA COLLECTION AND RESEARCH METHODOLOGY

The data for this study were collected at more than 40 sections of two-lane roads to determine the effect of gradient, lane width, directional split, shoulder’s condition and pavement roughness on capacity of twolane roads. The sections were so selected that the effect of each parameter could be studied individually. The details of these sections are given in Tables-1 to 4.

TABLE-1. DETAILS OF SECTIONS SELECTED FOR EFFECT OF GRADIENT
Section Section Identification Road Gradient Remarks No Width (m)

Section No	Section Identification	Road Width (M	Gradient	Remarks
1	. km-168 of NH-58 km-188 of NH-58	7.0 m	4%	+4% for up movement & -4% for down movement
2.	km-34 of NH-58	7.0 m	3.03%	+3.03% for up movement & -3.03% for down movement
3.	km-123 of NH-58	7.0 m	2.86%	+2.86 up movement
4.	Level section	7.0 m	2.63%	+2.63% up movement & -2.63% for down movement
5		7.0	0%	Both side movement

Estimation of Equivalency Factors

The main problem in developing the analytical speed-flow relationship is heterogeneity of traffic. The vehicles in the mix produce different impedance due to their varied static and dynamic characteristics. Hence simply adding the number of vehicles does not give the authentic speed flow relationship. For this reason, the vehicles are normally presented in terms of standard type of vehicle using certain conversion factors. Generally, passenger car is adopted as standard vehicle and therefore the factor is known as passenger car unit (PCU). Many researchers have developed methods to estimate PCU for a vehicle type. The interesting point to note is that each of these studies has resulted into different PCU values for the same type of vehicle. There exists large variation in PCU values being adopted in different parts of the world.
In the present study, the PCUs are calculated as follows. The basic concept used to estimate the PCU is that it is directly proportional to the ratio of clearing speed, and inversely proportional to the space occupancy ratio with respect to the standard design vehicle, a car, i.e.
Speed ratio of the car to the ith vehicle PCUi = ____ (Eqn. 1) Space ratio of the car to the ith vehicle

Where, PCUi = passenger car unit value of ith type vehicle

IV. TECHNICAL APPROACH AND ANALYSIS

The data were analyzed to study the effect of influencing parameters on capacity of two-lane roads. All vehicles were divided into 10 categories as shown in Table-7.

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Speed ratio of the car to the ith vehicle = Vc/Vi Space ratio of the car to the ith vehicle = Ac/Ai Vc = speed of car (km/h) Vi = speed of ith type vehicle (km/h) Ac = static (projected rectangular) area of a car (m2) Ai = static (projected rectangular) area of ith type of vehicle (m2)
Therefore,
Vc/Vi PCUi = __________ (Eqn. 2) Ac/Ai

The first variable of speed ratio in Equation (2) will be the function of composition of traffic stream as the speed of any vehicle type depends upon its own proportion and type and proportions of other vehicles. Hence speed of any vehicle type will be true representation of overall interaction of a vehicle type due to presence of other vehicle of its own category and of other types. The second variable represents the pavement occupancy with respect to car.
The PCU values for different categories of vehicles were computed at various sections and these are given in subsequent sections.

Effect of Grade
The PCU values for different types of vehicles with grade at different sections are given in Table-8. Further discussion on these values is given elsewhere (Chandra and Goyal, 2001)4. The PCU values given in Table-8 were used to convert all vehicles into equivalent number of passenger cars and speed–volume relationships were plotted. The capacity values with grade at different sections are given in Table-9. It indicates that each per cent of upgrade decreases the capacity by 2.61 per cent and each per cent of downgrade increases the capacity by 3.09 per cent.

TABLE-8. PCU FOR DIFFERENT TYPES OF VEHICLES AT DIFFERENT GRADIENT

S. No.	Gradient	PCU for					
		Bus	2 W	LCV	Cycle	CR	ADV
1.	+4%	3.7	0.22	1.99	0.45	1.744	4.335
2.	+3.03%	3.5	0.215	1.85	0.43	1.608	4.167
3.	+2.86%	3.443	0.213	1.8	0.42	*	4.016
4.	+2.63%	3.413	0.21	1.7	0.409	1.52	3.9
5.	0 %	3.1	0.205	1.55	0.4	1.45	3.7
6.	-2.63%	2.9	0.195	1.4	0.38	1.297	3.4
7.	-3.03%	2.75	0.19	1.35	0.37	1.287	3.2
8.	-4%	2.65	0.185	1.25	0.355	1.2	3

TABLE- CAPACITY OF SECTIONS WITH GRADE			
S. No.	Gradient	Capacity/lane (pcu/h)	% Change in capacity w.r.t level
1.	+4%	1175	10.30
2.	+3.03%	1210	7.63
3.	+2.86%	1062	18.93
4.	+2.63%	1214	7.33
5.	0 %	1310	0
6.	-2.63%	1397	6.64
7.	-3.03%	1438	9.77
8.	-4%	1486	13.43

Effect of Lane Width

The purpose of this part of study was to estimate capacity of two-lane roads with varying carriageway width. Data collected at sections given in Table-2 were analyzed to determine the effect of lane width. Table-10 presents the PCU values as derived at these sections using Equation (2). Figs. 1 to 3 show the variation in PCU for different types of vehicles with varying lane width at different sections.

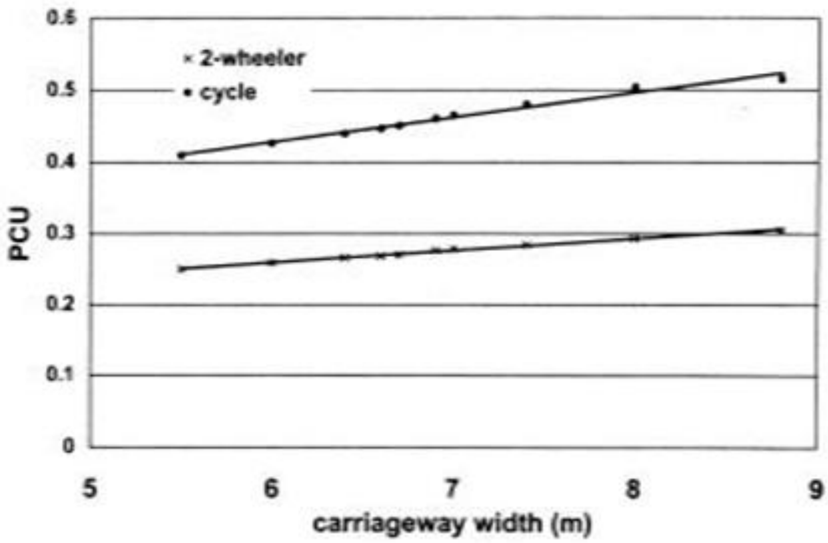

Fig. 2. Effect of carriageway width on PCU for cycle & 2-wheeler Classification of shoulders

In order to have better appreciation of results, the shoulders were divided into different categories depending upon their physical condition at time of data collection. The method suggested by Chandra and Dev Raj (1999)[6] was adopted for objective assessment of shoulders. The criteria of this classification is given below:

(i) Good: The shoulders on either side are properly maintained and minor or no settlement of gravel or earthen shoulders (less than 25 mm in depth) with the pavement edge. Shoulders can be used at reasonably high speed.

(ii) **Average:** Drop at pavement edge is 25-50 mm. Broken portion of the shoulders is less than 25 per cent. Shallow potholes are present but the shoulder can be used at low speed.

(iii) **Poor:** Drop at pavement edge is 50-100 mm. 25-50 per cent shoulders are either broken or removed. Deep potholes are formed in the surface. The shoulder can be used at considerably low speed only.

(iv) **Bad:** Drop at pavement edge is greater than 100 mm and more than 50 per cent shoulders are broken. Deep potholes in the shoulder surface are present. It cannot be used by vehicle even at low speed due to danger of overturning of vehicles.

Based on the above classification, the categories of various sections selected for study are given in Table

TABLE-17. CATEGORIES OF SHOULDER AT VARIOUS SECTIONS

Category of Shoulder	Sections
Average	25, 28, 31
Poor	26, 29, 32
Bad	27, 30, 33

Loss in width of carriageway

Physical condition of shoulders plays an important role for the development of full traffic capacity of a highway. The lateral placement of vehicles and thus utilisation of full carriageway width depends upon the width of carriageway and type and condition of shoulder. The field data given in Tables-5 and 6 indicate that the vehicles preferred to lower down their speed rather than coming on to the shoulders, which are poorly maintained. The loss in width of carriageway for different conditions is given in Table-18. As may be seen, the per cent loss in the width of the carriageway varies from 36.0 to 52.3 per cent for single moving vehicle depending upon the type of vehicle involved. During passing/overtaking, the percent loss in width of carriageway varies 18.0 to 35.4 per cent depending upon the type of vehicle involved in passing/overtaking manoeuvres and condition of shoulder. At all sections, the loss in width of carriageway for movement of a single car is greater than that for the movement of a HV and the loss in width of the carriageway during car-car passing/overtaking manoeuvres is more than that during HV-HV passing/ overtaking manoeuvres. Table-18 indicates that the loss in the carriageway width increases progressively as the condition of shoulder deteriorates, which directly affect the capacity of the road. Figs. 9 & 10 show the placement of a single vehicle for different conditions of shoulders. With average condition of shoulder about 50 per cent of cars and 50 per cent of HVs had their placement within 115 cm and 65 cm respectively, from pavement edge while for bad condition of shoulder, only 29 per cent cars and 10 per cent HVs had their placement within these limits.

TABLE-18. LOSS IN WIDTH OF CARRIAGEWAY RELATED TO CONDITION OF SHOULDER

Section No.	Per cent loss in effective width of carriageway of single vehicle		Per cent loss in effective with of carriageway during passing/ overtaking			Shoulder Condition
	Car	HV	Car-Car	Car-HV	HV-HV	
25.	44.8	38.6	26.6	20.8	18.6	Average
26.	48.3	40.6	30.8	24.0	20.3	Poor
27.	51.7	44.0	33.4	25.1	22.6	Bad
28.	46.0	37.7	27.4	21.4	18.0	Average
29.	49.4	39.7	31.4	23.2	20.9	Poor
30.	51.4	43.8	34.3	26.0	22.8	Bad
31.	45.1	36.0	25.4	20.6	18.9	Average
32.	48.8	38.6	32.6	24.3	21.4	Poor
33.	52.3	42.6	35.4	26.6	23.7	Bad

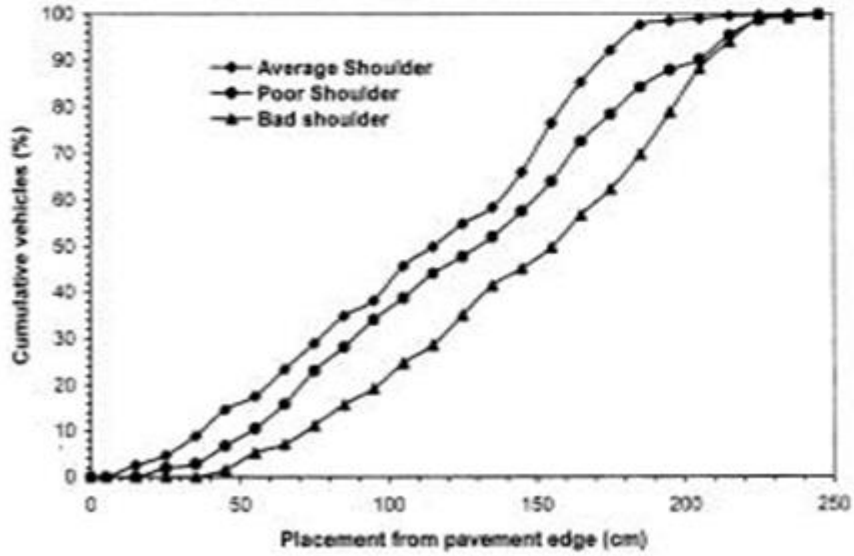

Fig. . Placement of car on two-lane road Reduction in speed during passing/overtaking manoeuvres

Spot speeds of vehicles were measured during passing/overtaking manoeuvres and during single free moving vehicle to estimate the average speed of each type of vehicle on a section. The percent reductions in speed of individual vehicle during above condition are given in Table. Two wheeler and bicycles were found to be unaffected by crossing vehicles due to their small size but other vehicles were forced to reduce their speed due to poor maintenance of shoulders. The maximum reduction in speed of a car while crossing another car is 10.7 per cent. Similarly, for the same condition of shoulder, maximum reduction in speed of a HV while crossing another HV is 28.4 per cent. It indicates that the vehicles reduce their speed considerably while crossing another vehicle. For good condition of shoulder the reduction in speed is very marginal, whereas for bad condition of shoulder it is quite substantial. The reduction is due to shoulder's influence on the drivers' behaviour during crossing. It should be noted here that the combined effect of speed reduction of individual vehicle and the loss in carriageway width on capacity will be much more significant.

Effect of Road Roughness

This part of study was aimed at determining the effect of road roughness on free flow speed (FFS) and capacity of two-lane roads. Therefore, the data were collected in two parts. In the first part, the observations were taken for road roughness and free flow speed of vehicles. The roughness measurements were taken on sections, free from the effect of curvature, gradient and intersections. The shoulders were in good conditions and road surface was not cracked or pot holed. The roughness was measured using British Towed fifth wheel bump integrator on the following sections of the two-lane highways.

(a) National Highway (NH) – 73 in the state of U.P.
(b) State Highway (SH) – 59 in the state of Uttaranchal
(c) National Highway (NH) - 7 in the state of Andha Pradesh

18 km length of NH-73, 5 km of SH-59 and 33 km of NH-7 was selected for roughness and speed measurements.

Free flow speed of a vehicle was measured using radar gun at every 100 m interval of a kilometre and the average speed for the entire kilometre was determined. Only 2 categories of vehicles viz. car and heavy vehicles (bus & truck) were considered for this part of study. About 10 vehicles of each category were observed for speed on each location.

In the second part of the study, speed-volume data were collected at 8 locations of two-lane highways. All sites were straight, level and free from any restriction to traffic movement. The video recording technique was used to collect the data for 4-5 hours on a typical weekday and these were analysed to plot speed-volume diagram.

Effect of roughness on free speed

The variation in flow free speeds of two principal vehicle categories viz. car and heavy vehicle with roughness is shown in Fig. 11. The free flow speed (FFS) decreases with roughness according to the following relationships.

Free speed of Car V_{ffsc} = 66.9 – 0.0034 * UI $R^2 = 0.91$ (Eqn. 6)
(43.05) (23.28)

Speed of HV V_{ffshv} = 51.6 – 0.0019 * UI $R^2 = 0.84$ (Eqn. 7)
(41.95) (16.38)

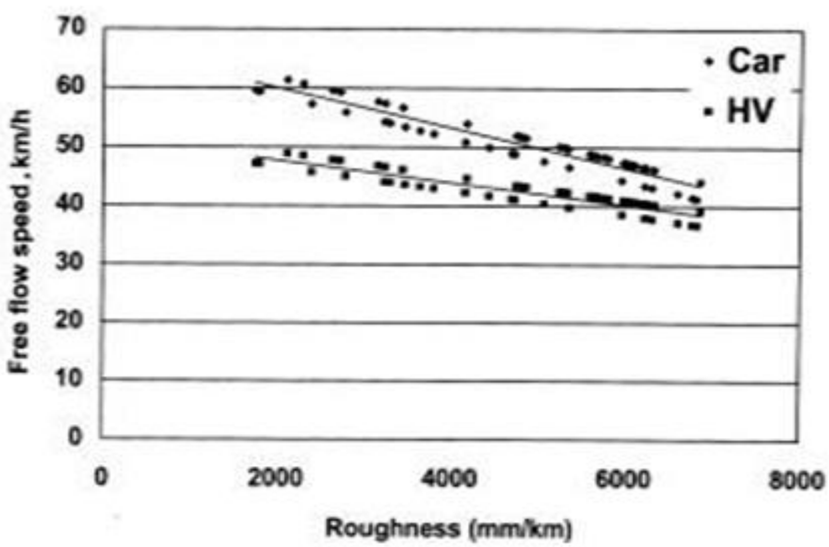

Fig.. Free flow speed related to road roughness

Where speed is in km/h and UI is unevenness index in mm/km. The values given in parentheses are the 't' values of coefficients, which are significant at 5 per cent level.

Effect of roughness on passenger car unit (PCU)

The PCU of a vehicle type was calculated by Equation (2). These are given in Table. Figs show the variation in PCU for different types of vehicles with road roughness at different sections. As may be seen, the PCU for a vehicle type decreases linearly with roughness, the slope of linearity depends on the type of vehicle. Non-motorized vehicles are not much influenced by road roughness while speed of motorized vehicles is greatly influenced. The fast moving vehicles are substantially influenced by road roughness while its effect on all other vehicle types is relatively low.

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Speed±Volume Relationship

Speed, density, and volume are the most important components of a traf®c stream for estimating the traf®c carrying capacity of a road. Since the measurement of traf®c density in a mixed traf®c situation is dif®cult, attempts have always been to concentrate on the speed±volume relationship for different type of roads. For the determination of a speed±volume relationship in heterogeneous traf®c conditions, the total vehicles recorded for each counting period were converted into an equivalent number of the PCU's using values given in Table 3.

In a mixed traf®c situation, a large variation in speeds among slow and fast moving vehicles exists. Therefore, the spot speed or the space mean speed, as normally calculated for the homoge-neous traf®c, cannot be considered for the mixed traf®c. It needs to be modi®ed to suit the heterogeneous traf®c conditions. For this purpose, many researchers suggest the use of a weighted

Table . Calculation of Passenger Car Unit Factors

Vehicle type	Relation between passenger car unit and carriageway width ~w!	R^2 value
Bus	PCU[b]_0.1114*w* _3.073	0.92
Truck	PCU_0.146*w* _4.40	0.95
LCV	PCU_0.097*w* _1.956	0.99
Tractor Trailer	PCU_0.103*w* _4.95	0.99
Three-Wheeler	PCU_0.168*w* _0.327	0.95
Two-Wheeler	PCU_0.017*w* _0.158	0.97
Cycle	PCU_0.034*w* _0.225	0.99
Rickshaw	PCU_0.054*w* _1.132	0.97

[a]LCV indicates light commercial vehicle.
[b]PCU indicates passenger car unit

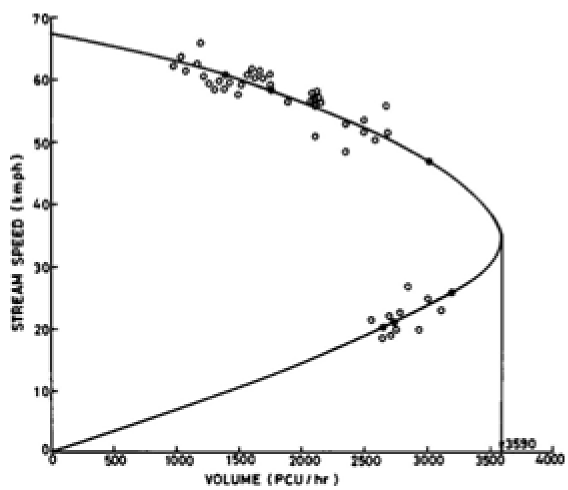

Fig. . Speed±volume relationship at section I

space mean speed or, simply, mean stream speed. To arrive at the mean stream speed, a trap of suitable length is made on the road and the speed of each category of vehicles considered for the count is calculated. The mean stream speed or weighted space mean speed is then given by

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$$V_m = \frac{\sum_{i=1}^{k} n_i v_i}{\sum_{i=1}^{k} n_i} \quad (3)$$

where k_total number of vehicle categories present in stream,
v_m _mean stream speed ~km/h!, v_i _speed of vehicle of category
i ~km/h!, and n_i _number of vehicles of category i.

The average stream speed calculated by Eq. ~3! was plotted against the traf®c volume. Typical curves showing speed±volume relationships are given in Figs. 4 and 5

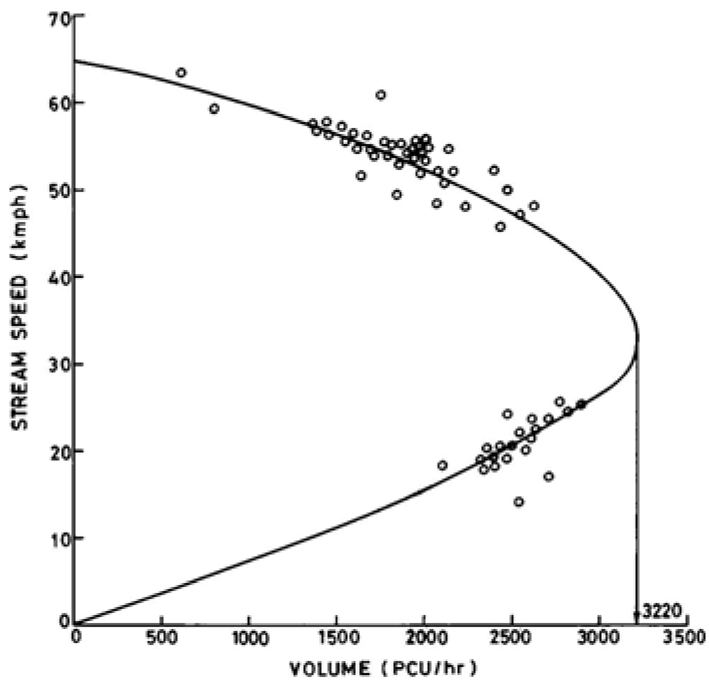

Fig. Speed±volume relationship at section IX

V. CONCLUSION

The Traffic data for urban road, the dynamic PCU values are found by us , Based on the parameters and Data obtained for capacity estimation the following conclusions have been drawn.

- The observed field capacity and simulated capacity is found to be ±5%
- The further increase in road width the PCU values for traffic composition are increases as well as capacity of road increases.
- Factors that are considered in the development of present model include side walk, cycle track, verge, service road, reserve, carriage way, provision for additional lane, median, unpaved shoulder and parking lane.
- It has been shown that the capacity function varies due to passage of pedestrians as there are interrelated to each other.
- Capacity function is also affected by cycle traffic cross flows and their intrusion into service lanes. It has been analysed that service lane connection towards arterial roads at junction points also affects the road

capacity. Reserve roads, medians, parking lanes on sub arterials and carriage ways tend to affect the value of road capacity at larger extent.

- The capacity values are different from the base capacity values and are nearly equal to the theoretical models which are calculated considering other factors.

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