Impact Factor (SJIF): 4.542

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 4, Issue 5, May-2017

Development of Model for Estimating Capacity of Roads for Heterogeneous Traffic Condition in Urban Area

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Abstract : The traffic is increased enormously due to rapid growth of vehicle ownership and increase of population in the urban area of India. The traffic management becomes very difficult due to higher growth rate of vehicles and non-availability of sufficient space in urban area. It leads to congestion, excessive delay and accidents on urban roads. Capacity is a key parameter for planning, design and operation of any type of urban roads. Indian Road Congress has recommended that Level of Service 'C' should be adopted for design of the urban roads. It is necessary to develop the mathematical model for estimating capacity of urban roads considering width of urban roads, traffic composition and other important parameters in existing condition. In the present study, the speed – flow relationships are developed for various mid-block sections of urban roads of Ahmedabad city. The capacity is determined for selected mid-block sections and compared with capacity recommended by IRC:106-1990. The mathematical models are also developed using multiple regression techniques and validated using statistical tools. The developed models are useful for determining the capacity of urban roads considering width of road, space mean speed, traffic composition of two wheelers, auto and cars and bus. It is observed from study that the recommended value of capacity, determined based on design service volume, suggested by Indian Road Congress (IRC) is less than the actual determined at field.

Key Words:
Capacity; Heterogeneous traffic; Design service volume, Level of Service; Traffic flow model

I. INTRODUCTION

The traffic is increased on the roads of urban area tremendously due to rapid growth in vehicle ownership and urbanization. The space availability for accommodating the vehicles is very less in the urban area. The estimation of capacity is important parameter for deciding the adequacy or deficiency of any traffic facility in the urban area. Capacity is the maximum hourly volume (vehicles per hour) at which vehicle can reasonably be expected to traverse a point or a uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions. The estimation of field capacity is essential for deciding the facilities to be provided for any type of roads. It helps the planner for fulfilling the requirement of improving traffic facilities on the road. Capacity of the urban roads is determined in relation to the level of service in India. Generally, level of service 'C' is adopted for design of the urban roads as per IRC: 106-1990[6]. As per level 'C', volume of traffic is around 0.7 times the maximum capacity. As per Highway Capacity Manual (2010) [5], the base capacity for all freeway segment varies with free flow speed. The capacity is measured in Passenger Car Unit (PCU) per hour. The composition of two wheelers, cars and auto are varying every year, which affects the capacity of roads. Due to variation in traffic composition, flow rate per hour is varying; hence capacity of road is also changed. It is required to develop mathematical model for estimation of capacity for the Ahmedabad city, which may be useful to the cities having similar characteristics.

II. LITERATURE REVIEW

Many researchers had carried out analysis for capacity of roads. The researchers had studied the effect of various variables on estimation of capacity of roads. Important research papers are studied and discussed for analysis of capacity for urban and rural roads. Satish Chandra et al (2003)[2] studied the effect of lane width on capacity under mixed traffic conditions. The effect of carriage way width on Passenger Car Unit (PCU) values of various categories of vehicles was analyzed. The models were developed for estimating Passenger car unit values for various types of vehicles. The relationships were derived between capacity and carriage way width. The adjustment factors were determined for estimating capacity of road. In this study, it was concluded that the capacity increases with increment of width of carriageway. The capacity of road was increased about 14% and 24% if roads are widened about 0.3m and 0.6 m respectively. Satish Chandra (2004)[3] carried out research on effect of road roughness on capacity of two-lane roads of National Highways and State Highways of India. The data of speed and volume were collected for free flow speed of

highways. He analyzed effect of road roughness of selected stretches. The study showed that free flow speed of a vehicle decreases with the roughness of the road surface. The estimated capacity of two lane roads with good pavement surface condition was about 3140 PCU/hour. It was concluded that the capacity reduces by 300 PCU/hour if road surface unevenness increased by 1000mm/km. Jun Yao et al (2009)[7] estimated Highway capacity using numerical solution approach. In this study, speed-flow-density relationship was derived for estimating roadways capacity and suggested numerical approach for deriving traffic stream parameters (flow, speed and density) by fitting two – regime model. The data sets were tested with past study and PATH programme of California. The capacity obtained at field was similar to the Van Aerde functional from_SPD_CAL approach and found differences about less than 6%. S. Velmurugan et al (2010)[10] determined capacity of multilane high speed corridors for heterogeneous traffic condition using the traditional and microscopic models. In this study, speed-flow equations and roadway capacities were critically evaluated. It was concluded that design service volume 'C' should be used as holding capacity for upgrading the multi-lane highways in plain terrain and lane changing behavior of vehicle affects the capacity of multilane highways. Ahmed Munawar (2011)[8] conducted various experiments for determination of capacity of urban road for Yogyakarta city. It was concluded that side friction is responsible factor for reduction of capacity. Nguyen Y. Cao et al (2012)[1] estimated capacity and Motorcycle Equivalent Units (MEU) on urban roads in Hanoi, Vietnam. The Passenger Car Unit (PCU) of different types of vehicles under heterogeneous traffic condition was developed to estimate Motorcycle Equivalent Units (MEU) of various types of vehicles in urban area. The estimated MEU for car, bus, minibus and a bicycle at road segments were 3.4, 10.5, 8.3, and 1.4 respectively. It was concluded that capacity of urban roads increases with the addition of number of road lanes. Hashim Ibrahim Hassan et al (2012)[4] studied on capacity loss due to effect of highway geometric. It was observed that capacity is reduced at curve due to reduction of speed and increases the spacing between the vehicles. Patel Chirag et al (2013)[9] estimated field capacity and level of service for urban arterial road for heterogeneous traffic condition for six lane divided road. The speed – flow relationship was developed for Surat city of Gujarat state of India. The field capacity for the six lane roads was determined and compared with recommended values given by Indian Road Congress (IRC). The derived capacity of six lane divided roads was 7450 vehicle per hour and 2480 vehicles per lane. In this study, the level of service for different range of v/c ratio for Surat city was established.

The present study is carried out to determine field capacity at mid-block sections of sub arterial and arterial roads of Ahmedabad city. The regression models are also developed considering width of road, observed share of different category of vehicles and space mean speed of vehicles for 4 lane divided (two ways) of Ahmedabad city of Indian state of Gujarat.

III. DATA COLLECTION AND DATA ANALYSIS

The study is carried out on various selected mid-block sections of Ahmedabad city of Gujarat state of India. All selected approaches are sub arterial roads of Ahmedabad city. The detail of the study area is shown in the Table 1.

Table 1 Details of selected mid-block stretches of urban roads

Sr. No.	Mid-block Stretch of the road	Width of road in meter (one sided)	Number of lanes and width of roads (As per IRC:106-1990)
1	Manav Mandir to Gurukul	10	4 lane divided (two way) / 14 m
2	Sattadhar cross road to Sun-n-Step road	8.8	4 lane divided (two way) / 14 m
3	Shastrinagae to Pragatinagar	10.7	4 lane divided (two way) / 14 m
4	C. G. Road	7.2	4 lane divided (two way) / 14 m

Inventory data are collected at the mid-block of the selected stretches of study area. Traffic data are collected on the selected stretches through videography for morning and evening peak hours from the selected mid-blocks. The length of mid-block section of 50 meter is marked on the urban road. The videography is carried out for the peak hours at selected stretches. The time taken by the vehicles from start point to end point is measured. The spot speed is determined considering distance travelled by vehicles to cross the start point and end point, divided by the time taken. The space mean speed is determined from the spot speed of each vehicles passing in the selected stretch crossing in unit interval. The traffic flow passing from start point and end points are measured for every 5 minute interval.

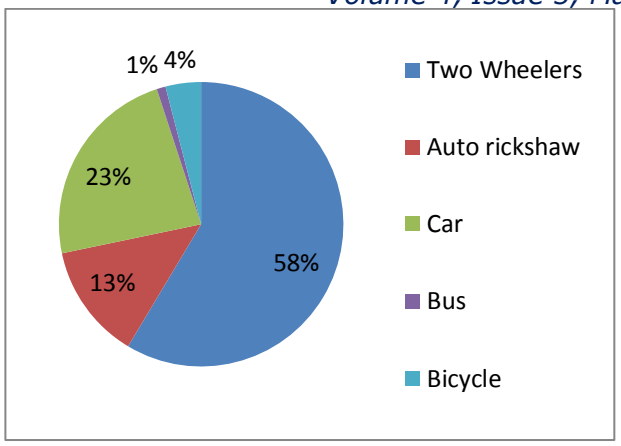

Figure 1: Traffic Composition at Manav mandir - Gurukul road

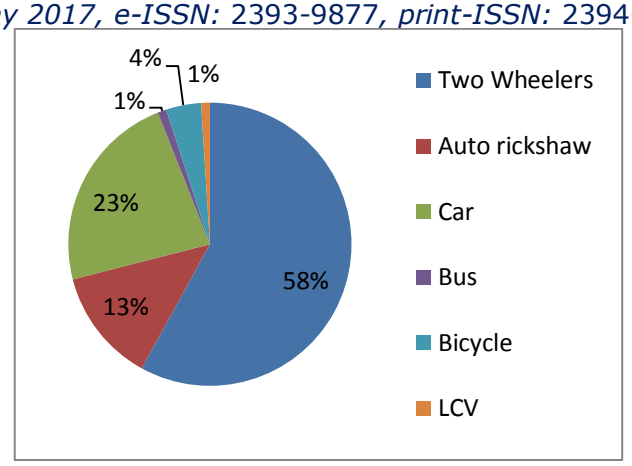

Figure 2 : Traffic Composition at Satadhar cross road to Sun n step club road

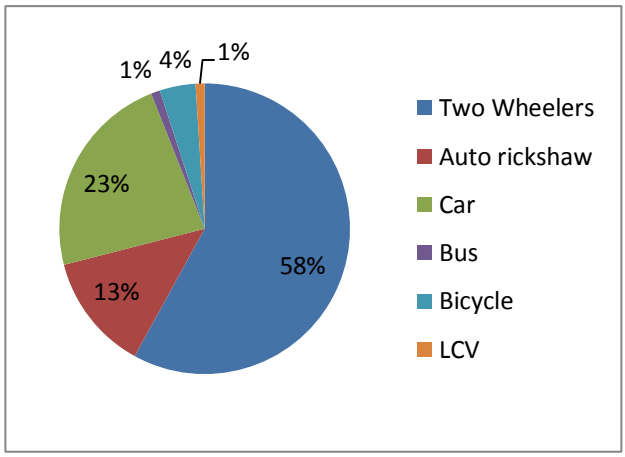

Figure3:Traffic Composition at Shastrinagar - Pragatinagar

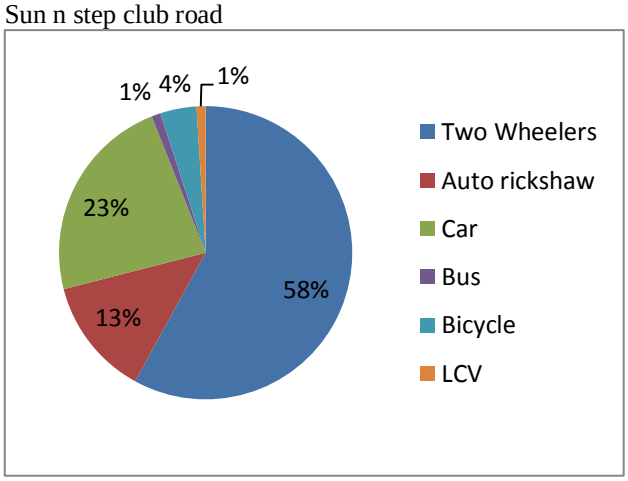

Figure 4 : Traffic Composition at C. G. Road

The observed average traffic composition on the selected stretches is presented from Figure 1 to Figure 4. The average traffic composition of two wheelers and cars are about 60% and 22% respectively. The traffic composition of two wheelers and cars are much higher than the remaining category of vehicle class. The heavy vehicles are not allowed in the urban area during 9 am to 9 pm. The average traffic composition of bus is 1% on the selected stretch. The traffic composition of Light Carrier Vehicle (LCV) is about 2% on the selected mid-block section. The average composition of bicycles is about 3% on the selected stretches. All vehicles are having different static and dynamic characteristics. The average speed of each vehicles and space consumed is different, which ultimately impacts the capacity of flow.

IV. DEVELOPMENT OF SPEED – FLOW RELATIONSHIP

The relationship between space mean speed and flow is developed for the selected stretch in the study area. The space mean speed – flow relationship are presented from figure 5 to figure 10. The traffic volume and space mean speed are determined at the mid-block section of various urban roads.

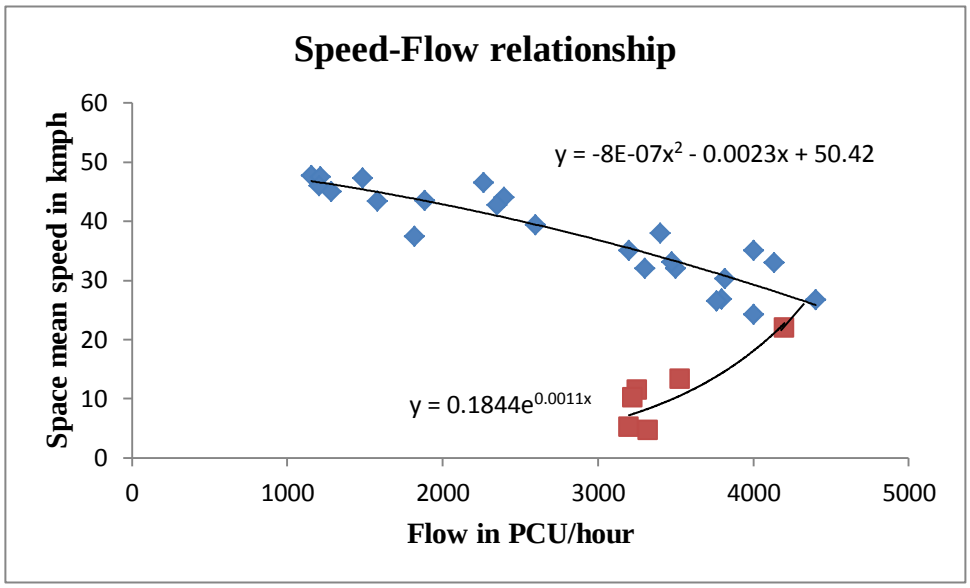

Figure 5 : Speed – Flow relationship for Manav mandir to Gurukul road

Speed–Flow relationship is presented for Manav mandir to Gurukul stretch in figure 5. Upper curve follows a second degree curve relationship between speed and flow for Manavmandir – Gurukul road as shown in equation (1).

$y = -8E\text{-}07x^2 + 0.0023x + 50.42$ (1)

The upper curve gives good result from speed of 47.65 kmph to 26.74 kmph. The developed relationship estimates flow of 4400 PCU/hour. R square value of upper curve is 0.8234 which shows good relationship between speed and flow. The equation (1) does not reflect effect of speed less than 26.74 kmph.

Lower curve follows an exponential relationship between speed and flow, as shown in equation (2).

$y = 0.1844e^{0.0011x}$ (2)

The lower curve gives good result from speed of 22 kmph to 5 kmph. The developed relationship estimates flow of 4200 PCU/hour in higher limit and 3197 PCU/hr. R square value of lower curve is 0.5656 which shows good relationship between speed and flow. The lower curve gives good result for forced flow condition. The equation (1) and (2) intersects at space mean speed of 26.74 kmph having maximum flow of 4400 PCU/hour, which is considered as capacity of 10 meter wide road of Manav mandir to Gurukul road.

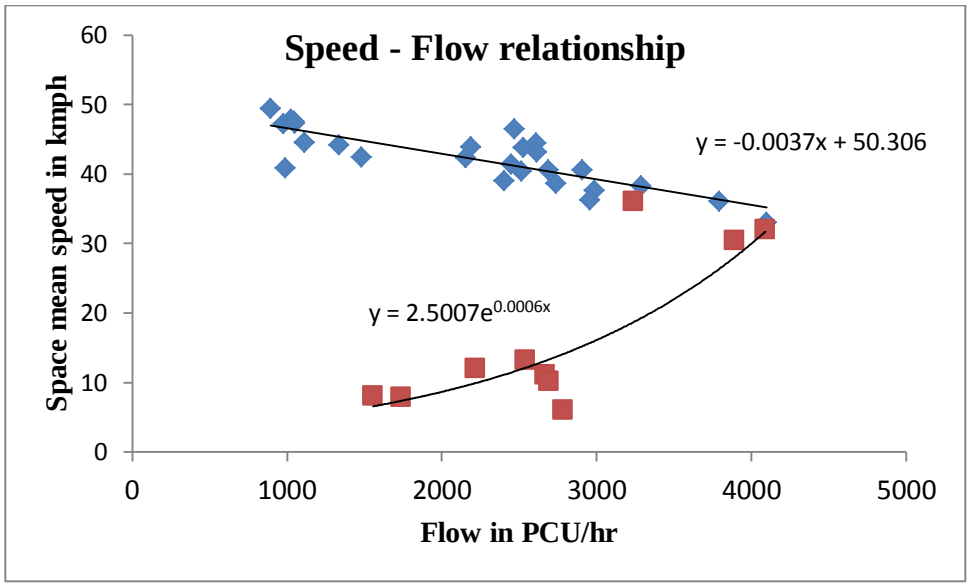

Figure 6 : Speed – Flow relationship for Satadhar cross road to Sun n step club road

Speed–Flow relationship is presented in figure 6 for Satadhar cross road to Sun n step club road. Upper curve follows a linear relationship between speed and flow for Satadhar cross road to Sun n step club road. The relationship between space mean speed and flow is shown in equation (3).

$$y = -0.0037x + 50.306 \quad (3)$$

The upper curve holds good result from speed of 33kmph to 49.4 kmph. The developed relationship estimates volume of 4100 PCU/hour in higher limit and 893 PCU/hr in lower limit. R square value of upper curve is 0.6753 which shows good relationship between speed and flow. The equation (3) does not reflect effect of speed less than 33 kmph.

Lower curve follows an exponential relationship between space mean speed and flow as shown in equation (4).

$$y = 2.57007e^{0.0006x} \quad (4)$$

R square value of lower curve is 0.6351 which shows good relationship between speed and flow. The lower curve gives good result for forced flow condition. The lower curve is valid for the speed from 6 kmph to 36 kmph. The equation (4) does not reflect effect of speed less than 6 kmph.

The equation (3) and (4) intersects at space mean speed of 33 kmph having maximum flow of 4100 PCU/hour, which is considered as capacity of 8.8 meter wide road of Satadhar cross road to Sun n step club road.

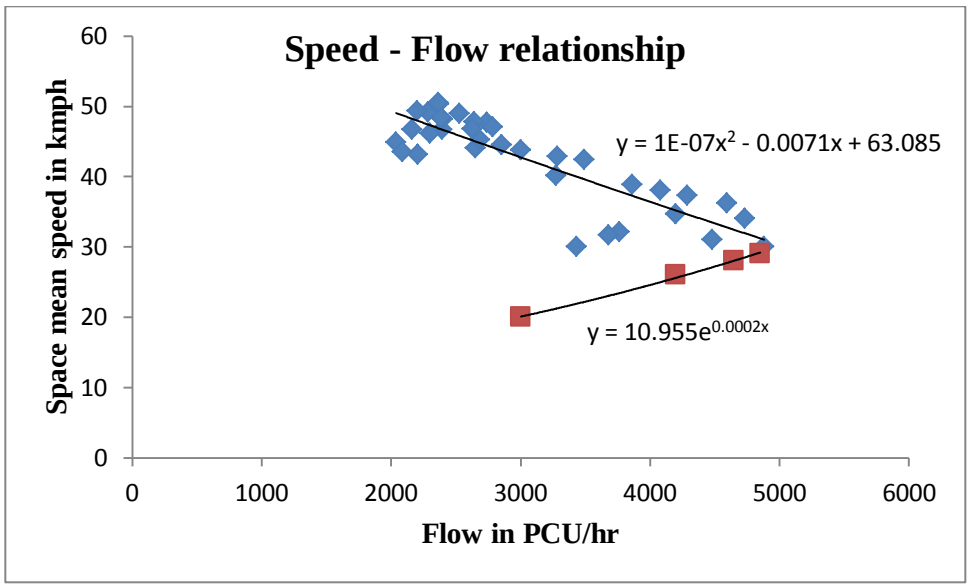

Figure 7 : Speed – Flow relationship for Shastrinagar to Pragatinagar road

Speed–Flow relationship is presented in figure 7 for Shastrinagar to Pragatinagar road. Upper curve follows a second degree curve relationship between speed and flow for stretch. The relationship between space mean speed and flow is shown in equation (5).

$$y = 1E\text{-}07x^2 - 0.0071x + 63.085 \quad (5)$$

The upper curve holds good result from speed of 34 kmph and 44 kmph. The developed relationship estimates volume of 4880 PCU/hour in higher limit and 2040 PCU/hr in lower limit. R square value of upper curve is 0.7292 which shows good relationship between speed and flow. The equation (5) does not reflect effect of speed less than 30 kmph.

$$y = 10.955e^{0.0002x} \quad (6)$$

Lower curve follows an exponential relationship between speed and flow. R square value of lower curve is 0.9964 which shows good relationship between speed and flow. The lower curve gives good result for forced flow condition. The developed relationship estimates volume of 4850 PCU/hour in higher limit and 3000 PCU/hr in lower limit. The lower curve is valid for the speed from 20 kmph to 29 kmph. The equation (6) does not reflect effect of speed less than 20 kmph. The equation (5) and (6) intersects at space mean speed of 30 kmph having maximum flow of 4860 PCU/hour, which is considered as capacity of 10.7 meter wide road of Shastrinagar to Pragatinagar road.

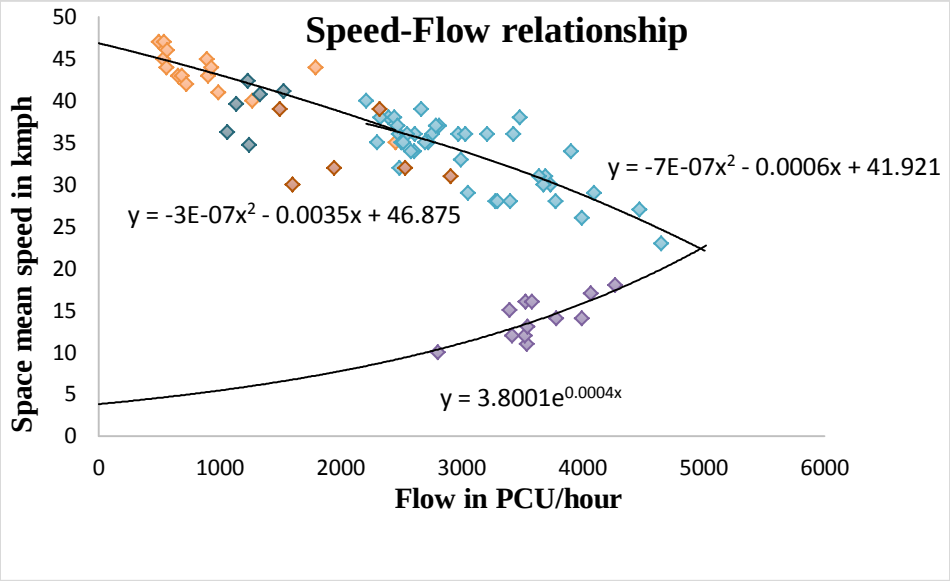

Figure 8 : Speed – Flow relationship for C. G. Road

Speed–Flow relationship is presented in figure 8 for C. G. road. Upper curve follows a second degree curve relationship between speed and flow for stretch. The relationship between space mean speed and flow is shown in equation (7).

$$y = -3E\text{-}07x^2 + 0.0035x + 46.875 \quad (7)$$

R square value of upper curve is 0.6023 which shows good relationship between speed and flow. The upper curve gives good result from speed of 31 kmph and 47 kmph. The developed relationship estimates volume of 2911 PCU/hour in higher limit and 500 PCU/hr in lower limit. The upper curve is valid for the speed from 31 kmph to 47 kmph. The equation (7) does not reflect effect of speed less than 31 kmph. Intermediate curve follows a second degree curve relationship between speed and flow for stretch. The relationship between space mean speed and flow is shown in equation (8).

$$y = -7E\text{-}07x^2 + 0.0006x + 41.921 \quad (8)$$

R square value of upper curve is 0.6014 which shows good relationship between speed and flow. The upper curve gives good result from speed of 23 kmph and 35 kmph. The developed relationship estimates volume of 5000 PCU/hour in higher limit and 2500 PCU/hr in lower limit. The intermediate curve is valid for the speed from 23 kmph to 35 kmph. Lower curve follows an exponential relationship between speed and flow. The relationship between space mean speed and flow is shown in equation (9).

$$y = 3.8001e^{0.0004x} \quad (9)$$

R square value of lower curve is 0.5528 which shows good relationship between speed and flow. The lower curve gives good result from speed of 10 kmph and 18 kmph. The developed relationship estimates volume of 5000 PCU/hour in higher limit and 2800 PCU/hr in lower limit. The lower curve is valid for the speed from 10 kmph to 18 kmph. The equation (9) does not reflect effect of speed less than 10 kmph. for forced flow condition. The equation (8) and (9) intersects at space mean speed of 23 kmph having maximum flow of 5000 PCU/hour, which is considered as capacity of 7.2 meter wide C. G. road.

V. CALCULATION OF CAPACITY BASED ON DESIGN SERVICE VOLUME

The capacity of urban roads is determined as per recommendation given in IRC:106-1990. Table 2 shows the recommended design service volume. IRC: 106-1990 has recommended that Level of Service (LOS) 'C' should be adopted for design of urban roads. As per level 'C', design service volume of traffic is around 0.7 times the capacity for the purpose of adopting design values.

Table 2 Recommended Design service volume and capacity (IRC:106-1990)

Sr. No.	Type of road	Width of road in meter (two way)	Total Design Service Volume recommended by IRC:106-1990 (PCU/hour)	Capacity of urban roads recommended by IRC : 106-1990 (PCU/hour)
1	4 lane divided (two way)	14	2900	4143

The maximum flow on the various selected mid-block sections is derived from figure 5 to figure 8. Table 3 includes the comparison of derived capacity and standard capacity as suggested by IRC:106-1990.

Table 3 : Comparison of observed capacity and estimated capacity

Sr. No.	Name of Urban road	Type of road	width of road in meter	Derived Capacity (PCU/hour/ direction)	Capacity recommended by IRC:106-1990 (PCU/hour)	% difference w.r.t. recommended value by IRC : 106-1990
1	Manavmandir to Gurukul	4 lane divided (two way)	10	4400	2958	(+) 49%
2	Sattadhar cross road to Sun-n-Step	4 lane divided (two way)	8.8	4100	2604	(+) 57%
3	Shastrinagar to Pragatinagar	4 lane divided (two way)	10.7	4860	3166	(+) 53%
4	C. G. Road	4 lane divided (two way)	7.2	5000	2645	(+) 89%

It is observed from Table 3 that derived capacity is much higher than the value recommended by Indian Road Congress. The capacity observed at Manav mandir to Gurukul stretch, Sattadhar cross road to Sun-n-step club and Shastrinagar to Pragatinagar stretch is about fifty percentage higher than the capacity recommended by IRC. The traffic moving towards city area is higher in the morning peak hours having majority of two wheelers, cars and auto. The capacity observed at C. G. road is 89% higher than the capacity recommended by IRC. Hourly flow rate is too much high at C. G. road due to availability of commercial market.

VI. DEVELOPMENT OF MODEL FOR ESTIMATING CAPACITY FOR URBAN ROADS

The models are developed considering width of road, traffic composition and space mean speed using Multiple Regression technique.

Model 1

Capacity, $C = 221W - 35S + 36TW + 48AUTO - 22CAR - 236BUS$ (10)

Where, W = Width of road in meter
S = Space mean speed in kmph
TW = Traffic Composition of Two Wheelers in a flow (%)
AUTO = Traffic Composition of Auto in a flow (%)
CAR = Traffic Composition of Cars in a flow (%)
BUS = Traffic Composition of Bus in a flow (%)

R square = 0.96

Model 2

Capacity, $C = 444W - 39S$ (11)

Where, W = Width of road in meter.
S = Space mean speed in Kmph

R square = 0.91

Variables	t observed	
	Model 1	Model 2
W	7.15	-6.90
S	8.01	19.94
TW	8.78	--
AUTO	6.54	--
CAR	-2.88	--
BUS	-5.76	--
absolute t	1.97	1.97

In Model-1, the absolute value of 't' is significantly high for width of road, space mean speed, traffic composition of two wheelers, auto, car and bus than absolute 't'. It can be concluded that the slope coefficient is useful in estimating the capacity of urban roads considering width of roads, space mean speed, and traffic composition of two wheelers, auto, car and bus.

In model-2, the absolute value of 't' is significantly high for width of road and space mean speed compared to absolute 't. It can be concluded that the slope coefficient is useful in estimating the capacity of urban roads.

VII. CONCLUSION

The estimation of capacity of urban roads is an important parameter for proper planning of the transportation system. The accurate determination of capacity is also important for reduction of congestion and delay on urban roads. Followings are the major outcome of the present study.

- The speed – flow relationships are developed for the selected stretches. It is also observed that derived capacity is higher than the value recommended by IRC:106-1990.
- Model 1 and Model 2 are developed for estimating capacity of urban roads considering width of road, traffic composition and space mean speed. The statistical significance of independent variables in the developed models are validated using 't' tests. From the statistical validation, it was inferred that width of road, traffic composition of two wheeler and auto significantly affects the capacity owing to high speed and ease in maneuverability.
- The model developed in this study, caters to the heavy heterogeneous traffic on the arterial and sub arterial roads of Ahmedabad city. It is observed that size, speed of each type of vehicle and road width of urban roads are varied, therefore, derived capacity is different at each selected locations.
- The traffic composition of two wheelers and cars is in the range of 53% to 65% and 23% to 30% respectively in the study area of Ahmedabad city of India. It is observed that traffic composition of two wheelers, auto, cars and bus significantly affects the capacity of urban roads due to varying characteristics of each group of vehicles.
- The models for estimation of capacity of urban roads are developed for one way movement of the selected stretch only. The same can be extended for two way movement in the urban roads.
- The developed models can be validated at other stretches of city having similar traffic characteristics on roads.
- The general model can be developed for two lane, four lane and six lane urban roads for estimating capacity.

Limitations of study:

- The present study is carried out on four lane divided (two way) roads of Ahmedabad city. The capacity is not derived for two lane divided (two way) and six lane divided (two way) urban roads due to existing side friction in city.
- The study does not include the impact of lane changing behaviour and psychology of road users, which also affects the capacity during peak hours.
- The terrain of Ahmedabad city is plain, so the present study does not include impact of gradient on capacity.

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