Mixed Traffic Speed–Flow Behavior under Influence of Road Side Friction and Non-Motorized Vehicles: A Comparative Study of Arterial Roads in India

Chetan R. Patel, G. J. Joshi

Abstract**—**Present study is carried out on six lane divided urban arterial road in Patna and Pune city of India. Both the road having distinct differences in terms of the vehicle composition and the road side parking. Arterial road in Patan city has 33% of non-motorized mode, whereas Pune arterial road dominated by 65% of Two wheeler. Also road side parking is observed in Patna city. The field studies using videography techniques are carried out for traffic data collection. Data are extracted for one minute duration for vehicle composition, speed variation and flow rate on selected arterial road of the two cities. Speed flow relationship is developed and capacity is determine. Equivalency factor in terms of dynamic car unit is determine to represent the vehicle is single unit. The variation in the capacity due to side friction, presence of non motorized traffic and effective utilization of lane width is compared at concluding remarks.

Keywords**—**Arterial Road, Capacity, Dynamic Equivalency Factor, Effect of Non motorized mode, Side friction.

I. Introduction

SUSTAINABLE urban transportation calls for efficient utilization of road space in cities in the most effective way while planning for any expansion or enhancement. At network level, functional performance of hierarchal roads according to their expected supply of mobility and accessibility is essential for desired quality of service to the road users. Arterial roads in metropolitan cities are designed to provide mobility to high volume of traffic between major traffic generators and attractors. Observations on such roads in Indian metropolitan cities show lack of control of road side activities like parking etc. and traffic operation in mixed mode with slow moving non-motorized vehicles along with the fast moving vehicles. Effect of these two phenomenon on traffic flow and hence on the carrying capacity of roadway should be analyzed to refurbish the functional performance requirement of arterial road in terms of speed.

Traffic on the most of the Indian cities is highly heterogeneous in nature. Further the hierarchy of the road network is not maintained in most of the cities. The hierarchy road pattern of any city has significant impact on effective transportation and traffic management system of the city. Accordingly, function of arterial road is to maintain the mobility requirement where as local street is to serve the function of access to land, however the arterial roads in Indian cities are not maintaining their characteristics of mobility because of side friction, presence of non motorized traffic, interruption due to intersection, which lead to reduction on capacity of urban arterial road. The research carried out in Indian also provides the feedback on the reduction of the capacity value of the arterial roads because of road side friction, presence of NMV, and numbers of lane. Ramanaya [2] observed that the capacity standards adopted in western countries do not take into account the mixed traffic characteristics prevalent in India The most referred guideline by IRC [3] also not discussed the capacity value for arterial road and capacity reduction factor.. Kumar and Rao [4] in their study represented linear relationships between speed and density. Chandra [5] reviewed the IRC guidelines for capacity estimation considering the National Highways as the study area, Chandra [6] studied the effect of shoulder condition on the speed of different types of vehicles and their placement on the road during passing and overtaking manoeuvres affecting the capacity values. The capacity is workout by [7] for two lanes NH is 3140 PCU/h. Based on the simulation study, [8] has found that the service volumes at LOS C for one-way traffic flow on 7.5 m and 11.0 m wide urban road spaces are 2,250 and 3,150 PCU per hour respectively. Velmurugan, S. Errampalli, M. & Ravinder, K [9] Derived DSV for varying types of divided carriageways has been evolved for multi-lane highways in India encompassing four-lane, six-lane and eight-lane. Joshi, Sinha and Patel [10] carried out the study on six lane dived urban road with predominance of two wheelers and develop speed-flow-density models in terms of vehicles, static PCU and dynamic vehicle equivalent factors they found capacity of 6905 Vehicles/hr, 5852 PCU/hr,13414 DTU/hr and 3097 DCU/hr for two lane arterial road. Patel and Joshi [11] carried out study on the six lane divided urban arterial road in Surat, Indian state of Gujarat, they established the speed flow relationship and capacity of 7450 vehicle/hr and 2480 Vehicles /hr/lane is determine. There is limited study on mixed traffic characteristic where carried out for urban arterial road to determine the capacity values and effect of the side friction and the NMV on the capacity. The present study is to attempt to capture capacity values with varied conditions of arterial road by considering the Pune and Patna city of India.

For the present study, six lanes divided arterial road sections in two metropolitan cities; Patna in state of Bihar and

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Pune in state of Maharashtra are selected to study these effects. In case of road section in Patna, the edge lane is found to be used for parking of vehicles and proportion of pedal rickshaws and bicycles in the traffic is @ 33%. Contrary to this, the selected section in Pune was largely free from road side activities and non-motorised vehicles were absent in the traffic stream. 16 hour manual traffic count was carried out to study hourly variation in traffic flow based on which peak and off-peak durations were identified for further detailed study of speed and flow through vidiographic survey. Classified traffic volume for 1 minute interval is extracted for 3 hours from video records of Patna and 4 hours for Pune section. Vehicular speeds are found by direct time-distance procedure by random selection of vehicle passing the trap area. Mixed traffic is converted into passenger car unit by modified homogenisation coefficient method dynamically and optimized to a single value of PCE for each vehicle type in the stream. Speed – flow relationships are developed for both the road sections and flow parameters at maximum flow level are derived and compared with the IRC specified values. Speed –flow models are verified for free flow speed observed during the study. Effect of road side friction and presence of NMVs is analysed by comparing service volumes and stream speeds at various volume-capacity ratios.

II. Study Methodology

For the study purpose two different cities are selected. The study is carried out to map traffic characteristics of urban arterial roads of varied characteristics. Details of survey and selected hours for the study are given in Table I. From Table I it can be observed that various day times are chosen to capture variation in traffic characteristics.

TABLE I
SURVEY SCHEDULE

Sr. No.	City (Road Name)	Selected Hours for the Study
1	Patna (Fraser Road)	06:00 to07:00, 08:30 to 09:30,13:00 to 13:30
2	Pune (Maharshi Karve Road)	07:00 to 8:00, 11:30 to 12:30, 13:00 to 14:00, 18:30 to 19:40

The field studies are carried out for traffic data collection at midblock sections of arterial roads. Due care is take that midblock is free from influence of intersection at upstream and downstream and the flat terrain with straight portion is consider. Videography technique is used to record the traffic behaviour for peak and off peak duration. The video camera is kept at the top of the building along the road side. Data has been compiled for one minute duration and analysis is carried out to study the traffic composition, flow-rate, density as well as vehicular speed variations.

The classified vehicular counts were made at the specified sections for one minute duration and flow rate is calculated by converting one minute volume to hourly volume. The speeds of the vehicles are also obtained by measuring travel time between two trap length of 30m.

Patna and Pune city have the different carriageway width and due to the side friction (Road Side Parking) the effective carriageway width is reduced in case of the Patan from 10.5m to 7.0m, whereas in the Pune city carriageway width is fully utilized. Figs. 1 and 2 show the carriageway width of both the city.

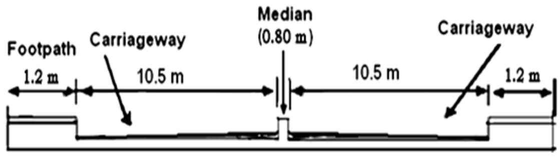

Fig. 1 Cross Section of Fraser Road (Patna)

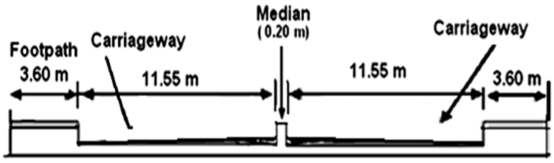

Fig. 2 Cross Section of Maharshi Karve Road (Pune)

Further both the city differs in the traffic composition Patna city having the major effect of Non Motorized Vehicles (NMV) around 33% whereas in Pune city major share is of Motorized Vehicle (MV).

III. Data Analysis

Data extracted from recorded videos of Patna and Pune cities are compiled and entered in Excel worksheets. Traffic composition, flow rate, peak hour factor and spot speeds of each vehicle category are calculated. In Patna city 2-Wheeler (2W), 3 Wheeler (3W), Car, Medium Bus (MB), Standard Bus (SB), Light Commercial Vehicle (LCV), Truck, Bicycle, Pedal Rickshaw are observed whereas in Puna City all vehicles expect Pedal Rickshaw are observed. City-wise data analysis is carried out and statistical parameter is described in the subsequent sections.

A. Traffic Composition and Flow Rate Analysis

Traffic composition and flow rate of Patan and Pune cities are given in Figs. 3 and 4 respectively. On Fraser Road of Patna it is observed that two-wheelers have major share of 31% in total traffic, followed by three-wheelers - 20%, car - 14%, bicycle-19% and pedal rickshaws 13%. Flow rate ranges from 240 veh/hr to 2520 veh/hr with an average of 1377 veh/hr. Peak hour factor in noon peak hour is 0.8 for 1 minute observation interval and is 0.92 for 5 min interval, this reflect that more or less same variation of flow is observed in peak hour.

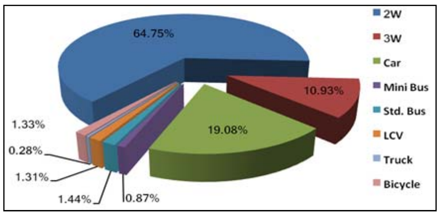

Fig. 3 Traffic composition on Fraser Road (Patna)

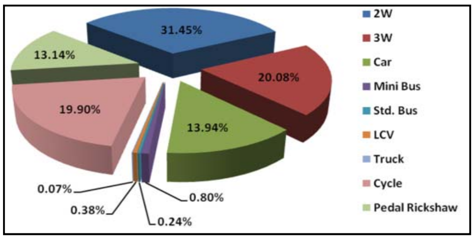

Fig. 4 Traffic Composition on Maharshi Karve Road (Pune)

Fig. 4 shows traffic composition on Maharshi Karve road of Pune city. It is observed that two-wheelers have major share of 65% in total traffic, followed by car- 19%, three-wheelers-11%, standard bus-1.5%, bicycle-1.3% and LCV-1.3%. Flow rate ranges from 1920 veh/hr to 13440 veh/hr. Peak hour factor in morning peak hour is 0.77 for 1 minute interval and is 0.83 for 5 min interval, which reflect slightly higher variation in flow during the peak hours compared to the Patan city.

B. Speed Variation Analysis

Spot speed of each vehicle category is determined by measuring time required by the vehicle to traverse a defined trap length of 30m marked on carriageway with white paints during video recording. As traffic volume is high, maximum six or actual number of vehicles whichever is less, are taken as samples for spot speed of each vehicle category in one minute time interval. Samples are taken randomly in such a manner that they are from whole one minute time interval without any bias and extreme outliers.

TABLE II
VEHICULAR SPEED CHARACTERISTICS

City	Flow Range	Statistical Parameters	2W	3W	4W	Min. Bus	Std. Bus	LCV	Truck	Bicycle	Ped. Rick.
PATNA	240 veh/hr to 2520 veh/hr	Min.	21.49	18.86	18.31	17.79	31.05	22.24	42.83	11.69	7.42
		Max.	52.06	38.28	57.27	52.68	40.11	41.77	42.83	19.75	14.43
		Avg.	37.78	30.97	39.87	31.74	37.56	31.50	42.83	14.91	10.71
		Std. Dev.	7.12	4.27	9.26	9.57	3.14	7.15	NA	1.84	1.48
		CV	0.19	0.14	0.23	0.30	0.08	0.23	NA	0.12	0.14
PUNE	1920 veh/hr to 13440 veh/hr	Min.	14.42	13.33	12.64	13.38	10.96	9.62	13.31	7.56	NA
		Max.	42.78	33.89	44.40	52.42	46.43	49.68	47.60	21.08	NA
		Avg.	28.27	23.63	25.78	26.47	25.11	24.15	23.90	13.81	NA
		Std. Dev.	6.51	4.45	6.75	8.30	8.87	7.54	7.52	3.56	NA
		CV	0.23	0.19	0.26	0.31	0.35	0.31	0.31	0.26	NA

In Patna city speed of 2w varies from 21.49 km/hr to 52.06 km/hr and 4w speed varies from 18.31km/hr to 57.27 km/hr. in Pune the speed range of 2w is form 14.42km/hr to 42.78km/hr and 4w speed varies from 12.64 to 44.40km/hr. Due to the presence of the NMV speed variation of the MVs are observed in wide range in Patna city whereas due to the side friction of the bus stop the speed reduction is observed in the Pune city compared to Patna.

Based on the above speed data the variation in the speed of all vehicles in Patna city are higher than the Pune city but the consistency in the speed of the vehicles are observed. The Speed variation range in both the city is same but the presence of NMV has greater variability in the speed data.

IV. EQUIVALENT FACTOR

There are various methods for determination equivalency factor i.e. Homogenization coefficient method, Walker's method, Headway method, multiple linear regression method and Simulation techniques. The approach suggested by [3] seems more suitable due to its simplicity and as it takes into account horizontal projected area and speed of vehicle which are prime influencing characteristics of a vehicle in heterogeneous traffic stream which was utilized here for the determination of Dynamic Car Unit (DCU).

The dynamic equivalent factor includes effect of vehicular speed on the traffic interaction and interference. The speed and maneuverability of the vehicles in stream is generally governed by the vehicles which has high proportion in the stream. In the present study, dynamic vehicle equivalent factors are estimated considering car as the reference vehicle. Using Satish Chandra's [3] modified homogenization co-efficient approach; effect of static characteristics is incorporated by comparing projected area of reference vehicle and the other vehicle in terms of area ratio. Speed ratio described as ratio of speed of reference vehicle to the other vehicle is adopted to include effect of speed differential as dynamic characteristics. It may be noted that area ratio remains constant for a vehicle type under all the flow condition, while speed ratio varies dynamically with the flow rate.

Mathematically,

$$DEFc = (Vc/Vy)/(Ac/Ay) \quad (1)$$

where, DEFc: Dynamic Vehicle Equivalent Factor considering 'car' reference vehicle; Vc/Vy: Speed Ratio; Ac/Ay: Area Ratio; Vc: Spot speed of 'car' as reference vehicle; Vy: Spot speed of 'y' vehicle; Ac: Projected area of 'car' as reference vehicle; Ay: Projected area of 'y' reference vehicle.

Speed and volume of vehicles are measured during every minute of traffic study for about four hours on selected arterial roads of six cities. Separate DEF are computed for each city to reflect the effect of roadway condition, traffic condition and local effect on DEF.

A. Area Ratio

Area ratio is important criteria for finding Dynamic Equivalent Factor in modified Homogenization coefficient method as shown in (1). Computed area ratios for each vehicle category using projected areas are shown in Table III.

TABLE III
AREA RATIO

Sr. No.	Vehicle	Projected Area of vehicle (m^2)	Reference vehicle (Car)
1	Two Wheeler (2W)	1.48	3.86
2	Three Wheeler (3W)	3.28	1.74
3	Car	5.72	1.00
4	Mini Bus	15.18	0.38
5	Std. Bus	25.73	0.22
6	Light Commercial Vehicle (LCV)	7.50	0.76
7	Truck	17.63	0.32
8	Cycle	0.86	6.65
9	Pedal Rickshaw	2.57	2.23

B. Speed Ratio

Speed ratio of reference vehicle and the vehicle category under consideration is the only dynamic parameter because area ratio remains constant for each vehicle category. The reference speed of the vehicle speed becomes higher compared to other vehicle DEF for that vehicle becomes high. This indicates greater impedance to the reference vehicle. Near capacity condition speed ratio becomes one because at that time all vehicles move at the same speed. Table IV shows speed ratio statistics for Fraser road of Patna city. It is observed that average speed of Car remains high than that of all other categories.

TABLE IV
SPEED RATIO STATISTICS FOR FRASER ROAD (PATNA)

Vehicle Category	Speed Ratio (Car as reference vehicle)							
	2W	3W	MB	SB	LCV	TRK	CYCL	PEDRXW
Max	1.62	1.91	1.78	1.70	1.25	-	4.24	7.11
Min	0.74	0.93	0.83	0.98	0.74	-	1.40	1.83
Average	1.06	1.28	1.26	1.24	1.10	-	2.65	3.79
Std. Dev.	0.16	0.21	0.26	0.26	0.15	-	0.63	1.22

Table V shows speed ratio statistics for Maharshi Karve road of Pune city. It is observed that average speed of car is higher than all the vehicles in the stream except 2-wheller because of greater maneuvering effect and absence of the Pedal Rickshaw.

TABLE V
SPEED RATIO STATISTICS FOR MAHARSHI KARVE ROAD (PUNE)

Vehicle Category	Speed Ratio (Car as reference vehicle)							
	2W	3W	MB	SB	LCV	TRK	CYCL	PEDRXW
Max	1.30	1.57	1.98	1.92	2.93	1.64	4.16	-
Min	0.64	0.78	0.70	0.54	0.48	0.44	0.84	-
Average	0.91	1.08	1.04	1.06	1.08	1.14	2.11	-
Std. Dev.	0.12	0.15	0.21	0.29	0.33	0.27	0.73	-

V. DYNAMIC CAR UNIT (DCU)

Dynamic car unit (DCU) is calculated for every 1 minute interval of observation. The area ratios for each vehicle type considering Car as reference vehicle are calculated and are shown in Section IV *A*. The speed ratios are also derived for these vehicles and are discussed in Section IV *B*. The DCU is then derived using (1). The calculated Dynamic Car Unit (DCU) Car as reference vehicles are given in following section.

TABLE VI
DYNAMIC CAR UNIT STATISTICS FOR FRASER ROAD (PATNA)

Vehicle Category	DCU (Car as reference vehicle)							
	2W	3W	MB	SB	LCV	TRK	CYCL	PEDRXW
Max	0.42	1.10	4.69	7.72	1.65	-	0.64	3.19
Min	0.19	0.53	2.18	4.44	1.02	-	0.21	0.82
Average	0.27	0.73	3.31	5.62	1.45	-	0.40	1.70
Std. Dev.	0.04	0.12	0.69	1.20	0.20	-	0.10	0.55
CV	0.16	0.16	0.21	0.21	0.14	-	0.24	0.32

It is observed that DCU values for 2W varies from 0.42 to 0.19 with average value of 0.27, for 3W DCU values varies from 1.10 to 0.53 with average value of 0.73, Variation of 4.69 to 2.18 with mean value of 3.31 DCU for MB, whereas for SB DCU values varies from 7.72 to 4.44 with average value 5.62 , for LCV DCU values varies from 1.65 to 1.02 with mean value of 1.45, for Cycle DCU value varies from 0.64 to 0.21 with average value of 0.4 and for pedal rickshaw DCU varies from 3.19 to 0.82 with mean value of 1.7.

TABLE VII
DYNAMIC CAR UNIT STATISTICS FOR MAHARSHI KARVE ROAD (PUNE)

Vehicle Category	DCU (Car as reference vehicle)							
	2W	3W	MB	SB	LCV	TRK	CYCL	PEDRXW
Max	0.34	0.90	5.20	8.73	3.86	5.14	0.63	-
Min	0.16	0.45	1.85	2.47	0.63	1.38	0.13	-
Average	0.24	0.62	2.73	4.83	1.42	3.58	0.32	-
Std. Dev.	0.03	0.09	0.55	1.33	0.44	0.84	0.11	-
CV	0.13	0.14	0.20	0.28	0.31	0.23	0.35	-

It is observed that DCU values for 2W varies from 0.34 to 0.16 with average value of 0.24, for 3W DCU values varies from 0.9 to 0.45 with average value of 0.62, Variation of 5.20 to 1.85 with mean value of 2.73 DCU for MB, whereas for SB DCU values varies from 8.73 to 2.47 with average value 4.83, for LCV DCU values varies from 3.86 to 0.63 with mean value of 1.42, DCU value for truck varies from 5.14 to 1.38 with average value of 3.58 and for Cycle DCU value varies from 0.63 to 0.13 with average value of 0.32.

Based on the above result the final values of the DCU are selected based on the average DCU value of the particular class of the vehicles which is represented in Table VIII.

TABLE VIII
DYNAMIC CAR UNIT FOR PATAN AND PUNE ARTERIAL ROAD

City	DCU (Car as reference vehicle)							
	2W	3W	MB	SB	LCV	TRK	CYCL	PEDRXW
Patna	0.27	0.73	3.31	5.62	1.45	-	0.40	1.70
Pune	0.24	0.62	2.73	4.83	1.42	3.58	0.32	-

VI. DEVELOPMENT OF STREAM FLOW MODELS

The theory of traffic flow enables us to describe the relationship between traffic flow, density and speed. Greenshield [1] studied the traffic flow relationships for the first time and proposed a linear function between speed and traffic density. Traffic flow behaviour is quantified through relationship between speed-density, Speed-flow and flow density in macroscopic approach. In the present study, traffic flow behaviour on urban arterial road section is analyzed under heterogeneous traffic environment. Following sections describe the various speed models developed to study the vehicular and stream speed behaviour in urban mixed traffic environment is modelled through various speed-flow-density models.

A. Q-K-V Models for Patna

Models are developed considering traffic characteristics of flow rate, speed and density in terms of veh/ hr, kmph and veh/km respectively. Data of uncongested regimes are observed on the field and data of congested regimes are predicted based on the Green shields Models. Inserting Green shield's speed-density relationship into the general speed-flow-density relationship yields:

$$q = (A - B*k)*k \text{ or } q = A*k - B*k^2 \quad (2)$$

where q = flow (vehicles/hour); A,B = constants; k = density (vehicles/mile, vehicles/kilometer).

Based on the Q-K-V relationship Density using flow and speed is worked out. Form the Q-K and Q-V relationship Jam density and free flow speed are determined. Using (2) with the different density values (0% to 100% of Jam density) and a speed values, flow values are calculated for the lower congested region.

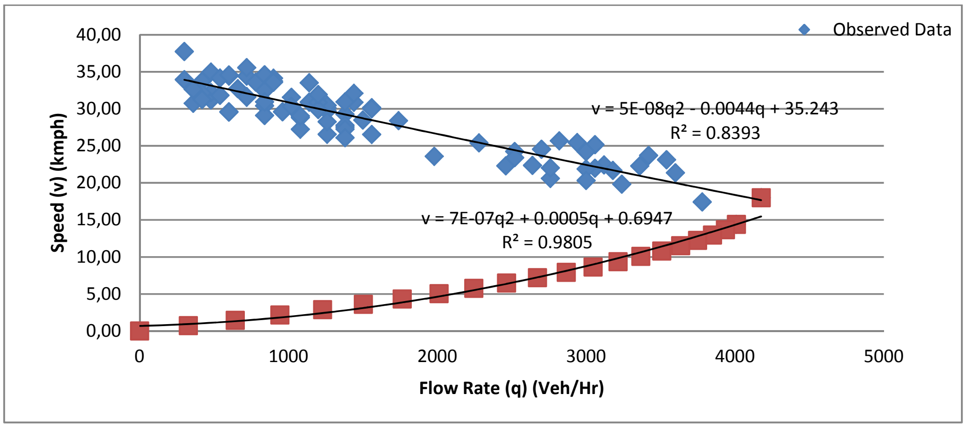

Fig. 5 Speed-Flow curve: Patna

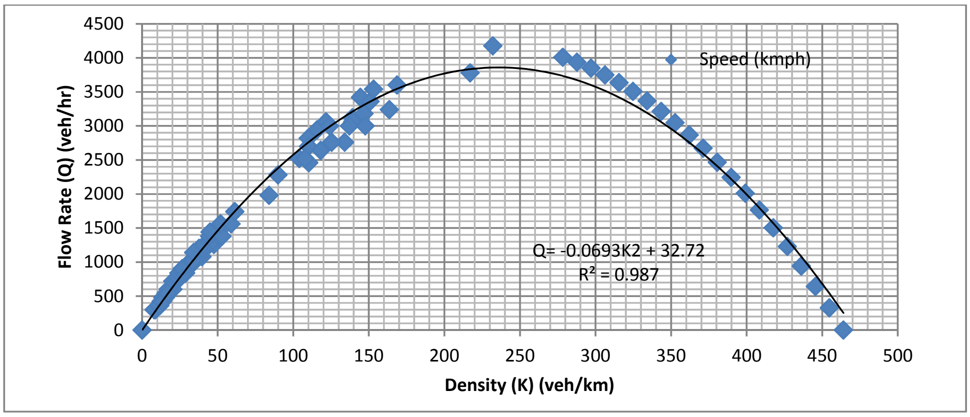

Fig. 6 Flow-Density Curve: Patna

Polynomial Quadratic equation is derived by the curve fitting through the observed data sets of Flow Density and shown in Fig. 5.

$$Q = -0.0693K^2 + 32.7 \qquad (R^2 = 0.98) \qquad (3)$$

TABLE XI
T STATISTICS FOR QUADRATIC EQUATION OF FLOW DENSITY

Coefficient	K^2	K
T	-105.6	136.9

The optimal (critical) density is derived by differentiating (3) with K and equating to zero, Optimal density, K_0 = 232 veh/km. Placing this density in (3), maximum discharge is obtained as Qmax = 3712 veh/h.

The jammed density (Kj) of 464 veh/km is obtained from the model. The capacity of the roadway is given by the maximum flow rate i.e. 3712 veh/km.

B. Q-K-V Models for Pune

Models are developed considering traffic characteristics of flow rate, speed and density in terms of veh/ hr, kmph and veh/km respectively. Data of uncongested regimes are observed on the field and data of congested regimes are predicted based on the Green shields Models.

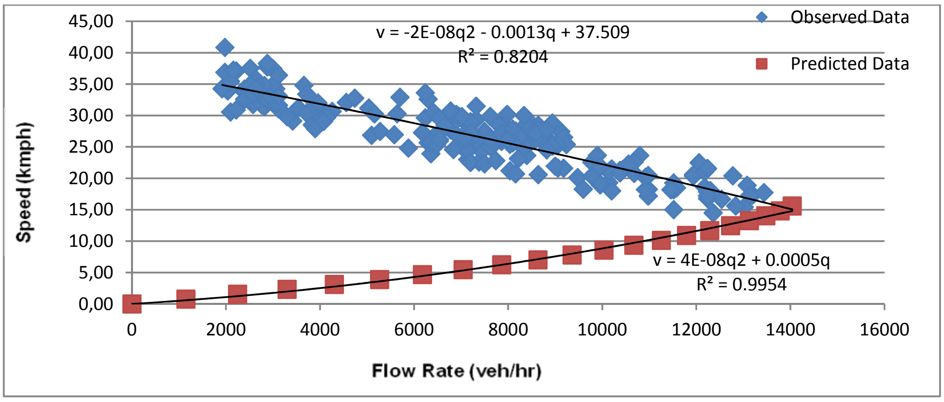

Fig. 7 Speed-Flow curve: Pune

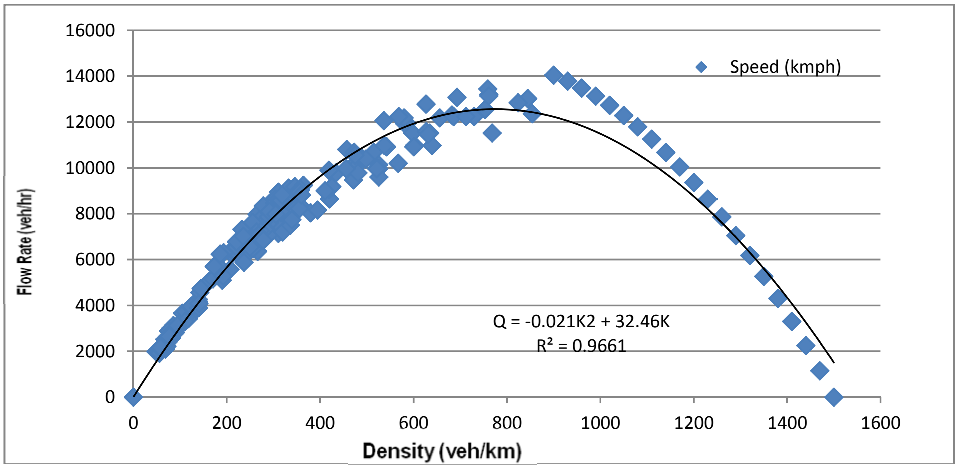

Fig. 8 Flow-Density Curve: Pune

Polynomial Quadratic equation is derived by the curve fitting through the observed data sets of Flow Density and shown in Fig. 8.

$$Q = -0.021K^2 + 32.46K \quad (R^2 = 0.96) \qquad (4)$$

TABLE X
T STATISTICS FOR QUADRATIC EQUATION OF FLOW DENSITY

Coefficient	K^2	K
T	-105.8	163.0

The optimal (critical) density is derived by differentiating (4) with K and equating to zero, Optimal density, K_0 = 758 veh/km. Placing this density in (4), maximum discharge is obtained as Qmax = 12292 veh/h.

The jammed density (Kj) of 1516 veh/km is obtained from the model. The capacity of the roadway is given by the maximum flow rate i.e. 12292 veh/km.

VII. Conclusion

Indian traffic differs significantly from western condition in many respects. The vehicles mix is much more varied with many poorly performing vehicles. Also the road side parking, Presence of the NMV reduced the speed and the carrying capacity of the road. The study is carried out to analyze the traffic flow characteristic, classified vehicular volume and speed behavior on midblock section of divided urban multilane arterial road of Pune and Patna cities of India. Both the arterial roads having difference condition of the carriageway and the composition. Based on the study it is observed that arterial road of the Patna city having road side parking and because of that effective utilization of the carriageway is only of 7.0 m and the presence of the bicycle and pedal rickshaws the speed reduction is observed. The classical speed flow model based capacity of both the roads is worked out in vehicles/hr and DCU/hr. Table XI depicts the various traffic characteristics of Pune and Patna Arterial road.

TABLE XI
Capacity of Urban Arterial Road of Indian Cities

City	Effective Carriageway width (m)	Capacity (veh/hr)	Capacity (DCU/hr)	Capacity (DCU/hr/lane)	Jam density (veh/km)	Free Flow Speed (kmph)
PATNA	7.0m	4060 veh/hr	2224 DCU/Hr	1112 DCU/Hr/lane	464 veh/km	35 kmph
PUNE	11.6m	14200 veh/hr	6405 DCU/Hr	1932 DCU/Hr/lane	1516 veh/km	41 kmph

Based on the above study the significant difference in the capacity value is observed. The capacity of the urban arterial road is greatly affected by effect of lane width, presence of NMV and effect of side friction. Patan having the carriageway width of 10.5m but due to side parking the effective utilization of the lane is only 7.0m which result into 57% reduction in the capacity. Also due to the side friction and presence of the NMV the 14% reduction in speed is observed in Patna city compared to Pune city.

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