**Heterogeneous Traffic Characterisation and Flow Behaviour Modeling for Metropolitan Arterial in India**

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**Abstract:** Arterials in metropolitan cities are expected to provide mobility to high volume of traffic. Realistic understanding of traffic flow behaviour for such vital urban roads is essential for traffic operation planning and management for ensuring desirable level of service. Metropolitan cities in India carry variety of vehicles with varied static and dynamic characteristics with predominance of two wheelers. The interaction in the midblock section between different types of vehicles significantly varies with the flow rate and therefore has varied effect on the equivalency of vehicle and the service volume. In present study, the traffic characterization on dynamic scale is carried out by considering two wheeler and car as reference vehicles. Speed-flow-density relationships are developed using dynamic vehicle equivalent factors. The results are compared with the static passenger car equivalent values and corresponding capacity for the selected arterial.

**Key Words:** Dynamic Vehicle Equivalent Factor, Flow Rate, Speed, Density

1. **INTRODUCTION**

Of late, importance of the metropolitan cities in national economic growth has been truly realized and schemes for improvement of road systems of these cities are initiated in number of metropolitan cities in India. Particularly, the arterial road system in any city caters to huge travel demand along with the mobility requirements. For efficient planning and implementation of traffic control and road development programmes, it is essential to quantify the traffic flow behaviour by appropriate characterization of the variety of vehicles using the same road space without segregation and loose lane discipline.
Expressing traffic volume as the number of vehicles passing a given section of road per unit time will be inappropriate when several type of vehicles with widely varying static and dynamic characteristics are present in the traffic stream. The problem of measuring such a heterogeneous volume has been addressed by converting the different types of vehicles into equivalent passenger cars and expressing the volume as passenger car unit (PCU) per hour. As traffic movement under fairly homogeneous traffic condition with cars constituting about 80% or more of the vehicle displays lane discipline, the volume or capacity under such situation may be expressed in terms of PCU per hour per lane. However, the pattern of occupancy of road space by vehicles under heterogeneous traffic condition differs significantly from that of homogeneous traffic.

Vehicles in a heterogeneous traffic stream with widely varying characteristics occupy any convenient lateral position on the road without any lane discipline, based on the availability of space. Although there are several factors that influence the PCU value of a vehicle type, traffic volume and composition are the important factors for a given roadway, influencing the amount of interaction between vehicles and traffic stream, and hence the PCU values of different types of vehicles. Of the two factors, namely volume and composition, the Indian Road Congress (IRC) has considered only the effect of traffic composition to a limited extent, and, based on field – observed traffic data, has recommended PCU values for different types of vehicles on Indian roads for two levels of composition (5% and 10% or more) of the subject vehicle which needs to be reexamined in present context with high level of motorization. Such equivalent factors are termed as Static Passenger Car Units (Static PCU) as they remain constant over whole range of traffic volume.

Chandra S. and P.K. Sikdar (2000) have studied the factors affecting PCU in a mix traffic situation on urban roads in India. The observations are that PCU for a vehicle type decreases with an increase of its own proportion in the traffic stream. Another significant observation is that PCU of a vehicle type depends on the speed differential with car in the traffic speed. If the speed differential increases with respect to car than PCU of the vehicle type will increase. Shah Pankil and Varia H. R. (2007) have also studied urban road link capacity determination using Dynamic PCU concept. Based on detailed study and analysis carried out for different widths of divided roads of Ahmedabad city in India, it is concluded that the dynamic PCU (DPCU) values for 2-wheeler, 3-wheeler and bicycle are less than static PCU values recommended by IRC for all the roads. The capacity of road sections calculated using DPCU is found to be much lesser than static PCU (SPCU) based capacities recommended by IRC. Arasan V. T. and Arkatkar S. S. (2007) have studied effect of gradient on vehicles of heterogeneous traffic on intercity roads in India through simulation. The study reports that the PCU value of a vehicle type considerably varies with variation in traffic volume as well as the gradient of the road. Arasan V.T.and Krishnamurthy K. (2008) studied the effect of traffic volume on PCU of vehicles under heterogeneous traffic conditions through micro-simulation technique considering 7.5m wide and 400m long road stretch. Traffic volume is found to influence PCU values of different vehicle types.

Present study is therefore carried out for traffic characterization in heterogeneous environment with predominance of two wheelers and developing speed-flow-density models in terms of
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vehicles, static PCU and dynamic vehicle equivalent factors for arterial road with access controlled mid block section in a metropolitan city in India.

2. METHODOLOGY

Most of the metropolitan cities in India (population between 1 million to 5 million) have two wheelers as a major vehicle type on their roads. For the present study, 500m long mid block section of a six lane divided arterial with service lane on either side in Surat city in Gujarat State of India is selected. The road is leading to the airport, sea port and major recreational spots of the city. Stretch begins with a rotary junction and ends with access uncontrolled carriageway. Trap length of 50m is marked at a distance of 150m from the junction to ensure stability of flow. Manual classified volume count is carried out for 5 minute interval for 16 hours in a weekday. Based on hourly traffic flow pattern, two peak hours and three off peak hours are identified for detailed survey through videographic technique. The road attracts lot of traffic from the city during week end as a recreation and outing corridor. Hence, videographic survey on Sunday evening peak hour is also carried out to capture near capacity condition. Classified spot speeds are measured manually and also from videographic survey for the three peak and three off peak hours. Speed, volume and density data are compiled for every 5 minute interval for six study hours.

Defining equivalent vehicle is one of the basic objectives of the present study. Heterogeneous traffic is expressed in terms of this equivalent vehicle by applying factors which reflect the effect of addition of one vehicle other than the equivalent (reference) vehicle on the average speed of all the reference vehicles under prevailing roadway, traffic and control condition. The amount of interference experienced by a vehicle from other vehicle at a location is a function of the traffic volume and relative static and dynamic characteristics of two vehicles under given roadway conditions. The most effective measure of the relative interaction is the difference in speeds of two vehicle types of different sizes. Also, the vehicle type dominating the traffic composition is expected to have dominant effect on the behaviour of other vehicles. As two wheelers form nearly half of the traffic flow, equivalent factors are derived by considering two wheeler as the reference vehicle type in addition to car.

In general, five methods are available for estimation of PCU of road vehicles. They are homogenisation coefficient method, Walker’s method, headway method, multiple linear regression method and simulation technique. The PCU of a vehicle type by homogenisation coefficient method can be estimated by comparing the theoretical maximum capacity of road under ‘passenger cars only’ condition with the ‘subject vehicle only’ condition. The PCU of the subject vehicle is expressed as \((\frac{L_i}{L_c})/ (\frac{V_i}{V_c})\), where \(L\) is the length and \(V\) is the speed of the subject vehicle - i and car. Chandra and Sikdar (2000) have successfully applied homogenisation co-efficient method by replacing length of the vehicle with the horizontal projected areas of the vehicles in mix traffic conditions. The other three methods are not suitable for estimation of PCU for vehicles under heterogeneous traffic conditions due to inherent assumptions of behaviour of homogeneous traffic and also rigid mathematical formulations. Simulation technique is a versatile tool to model complex systems by generating wide range of operating conditions, however, has limitation to fully replicate the mix traffic behaviour.
Homogenisation co-efficient method is therefore used for deriving the equivalent vehicle factors dynamically with change in traffic flow rates and hence the speed of vehicles. Relationships between speed – density, density-flow and flow-speed are derived by characterizing traffic in terms of vehicles (veh), static passenger car units (SPCU), dynamic two wheeler units (DTU) and dynamic car units (DCU) for free flow regime. Static Passenger Car Units are derived by applying PCU values 0.75 for two wheeler (for composition >10%) and 2.0 for three wheelers (for composition > 10%) on urban roads as recommended by IRC:106(1990). Traffic flow parameters like capacity, optimum density, free flow speed, speed at capacity and jam density are also found out.

3. FIELD STUDIES

The selected stretch of arterial road has 3 lanes of 3.5m each and service lane on both directions and a median dividing the carriageway. The road is called Gaurav Path connecting Athwa and Dumas zones in South West Sector of Surat City. The data requipink for the study includes composition, classified volume, density and classified vehicular speed during durations of a day when traffic flow rate and hence the behaviour of traffic changes significantly. Manual and videographic techniques are used for the collection of data. As urban roads have distinct peaks and off peaks of volume in a day, 16 hour classified volume count from 6 am to 10 pm on a week day was conducted to capture hourly flow variations in both the directions. The selected durations of week day peak hours are 9am – 10 am (Morning Peak Hour: MPH), 6pm – 7 pm (Evening Peak Hour: EPH) and off-peak hours are 7 am – 8 am (Morning Off Peak hour: MOP), 1pm – 2 pm (Noon Off Peak hour: NOP) and 9pm to 10 pm (Evening Off Peak hour: EOP). Sunday Evening Peak hour (SEP) of 6 pm – 7 pm is also selected for the study. From 16 hour survey, it is observed that 2-wheeler (2W), car (4- wheeler -4W) and 3-wheeler (3W) constitute about 96-98% of total traffic volume. Other modes have very negligible share of 2-3%. 2-wheeler traffic has maximum share of 58%. 3-wheeler and 4-wheeler also have major contribution of about 20% each in the stream.

The spot speed is measured by the direct time –distance procedure for reference distance of 50m. The free flow speed study is carried out by taking 30 samples of each mode in early morning between 4 am to 6 am. Observed mean free flow speed is 66 kmph (kilometer per hour) for 4W whereas free flow speed for 3W is 45 kmph and 61 kmph for two wheelers. Spot speed data of 2-wheeler, 3-wheeler and car is obtained from videographic survey as well as manual method for selected peak and off peak hours. Two-wheeler speed varies from 25 to 57 kmph. Speed variation in case of 4W is less compared to 2W. 3W speed is found to vary from minimum 24kmph during Sunday evening peak hour to 51 kmph during weekday noon off peak hour.

4. DYNAMIC VEHICLE EQUIVALENT FACTORS

Normally mixed traffic is expressed in terms of passenger cars. The static equivalency of a vehicle with respect to a standard passenger car is established by comparing the capacity of a roadway to pass maximum number of standard cars with maximum number of other type of vehicle in homogeneous traffic conditions. It is evident that the effect of interference from other
vehicles to the movements of the reference vehicle is significantly affected by the flow rate which in turn affects the speed of the vehicles. Therefore, for the given composition and roadway conditions, the vehicle equivalent factor is most likely to vary as the flow rate and speed of the stream change from time to time. This is more relevant in urban areas where hourly variations of flow rate are quite significant as discussed earlier. Under the circumstances, it is desirable to derive the vehicle equivalent factors which take care of the fluctuations in stream speed and also the speed of the individual vehicles for the urban roadway. Such vehicle equivalent factors vary dynamically as the speed of the reference vehicle in the mixed flow changes and hence are called Dynamic Vehicle Equivalent Factors (DVEF).

4.1 Dynamic Vehicle Equivalent Factor: Approach

The dynamic vehicle equivalent factor includes effect of vehicular speed on the traffic interaction and interference. The speed and maneuverability of the vehicles in the stream is generally governed by the vehicle which has high proportion in the stream. In the present study, dynamic vehicle equivalent factors are found considering two wheeler as well as car as the reference vehicle. The terrain is flat and road stretch is straight and free from effect of intersections and hence vehicles move at a constant speed. Homogenisation co-efficient method as suggested by Chandra and Sikdar (2000) is applied for computing vehicle equivalent factors for a small time interval. Effect of static characteristics is incorporated by comparing projected area of reference vehicle and the other vehicle in terms of area ratio (α). Speed ratio; described as ratio of speed of reference vehicle to the subject vehicle; is adopted to include effect of speed differential as dynamic characteristic. It may be noted that while area ratio (α) remains constant for a vehicle type under all the flow conditions, speed ratio (γ) varies dynamically with the flow rate. Mathematically,

\[
DVEF_x = \left(\frac{\gamma}{\alpha}\right)
\]

Where,

- \(DVEF_x\) = Dynamic Vehicle Equivalent factor considering ‘x’ reference vehicle
- \(\gamma_{x,y}\) = Speed Ratio during a time interval = \(V_x/V_y\)
- \(\alpha_{x,y}\) = Area Ratio = \(A_x/A_y\)
- \(V_x\) = Spot speed of ‘x’ reference vehicle during a time interval
- \(V_y\) = Spot speed of ‘y’ subject vehicle during a time interval
- \(A_x\) = Projected area of ‘x’ reference vehicle
- \(A_y\) = Projected area of ‘y’ subject vehicle

Number of observations of speed of 2W, 3W and 4W are taken during every 5 minute interval of traffic study for 6 hours. Accordingly, dynamic vehicle equivalent factors \(DVEF_{2w}\) (2 wheeler as reference vehicle) and \(DVEF_c\) (Car as reference vehicle) are derived by placing observed values of speed of reference and subject vehicles during a time interval. The observed average dimensions for the vehicles are shown in table 1.
Table 1 Vehicular dimensions

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Overall dimension (m)</th>
<th>Area of Vehicle (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Breadth</td>
</tr>
<tr>
<td>Car (4W)</td>
<td>4.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Three-wheeler (3W)</td>
<td>2.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Two-wheeler (2W)</td>
<td>1.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Area ratios are 0.17 and 0.42 for 3W and 4W considering 2W as reference vehicle and 5.93 for 2W and 2.46 for 3W when car is considepink as reference vehicle.

4.2 Computation of Dynamic Vehicle Equivalent Factors

Dynamic Vehicle Equivalent Factors are calculated for every 5 minute interval of observation. The area ratios ($\alpha$) for three vehicle type 2W, 3W and 4W considering 2W and 4W as reference vehicle are calculated and are shown earlier. The DVEF are then derived using equation 1. For example, during certain time interval, the average spot speed of cars is 44.5 kmph and that of 2W is 33.45 kmph, then the speed ratio for calculating DVEFc will be $44.5/33.45= 1.33$. As the area ratio for 2W is 5.93 when car is considered as reference vehicle, the DVEFc for 2W is $1.33/5.93 = 0.22$. The 2W volume during this time interval is then multiplied by 0.22 to derive the Dynamic Car Units (DCU). Similarly, DVEFc is derived for 3W to convert 3W volume into DCUs. The DVEF for the reference vehicle; either 2W or 4W; is always 1. As the vehicular speeds vary during different time intervals under the influence of volume, the DVEF and DVEFc values are also varying significantly. Average DVEF values for 3W are found to vary from 4.57 to 3.02, whereas it varies from 5.94 to 4.72 for 4W. The average 2W DVEFc values are found to lie in the narrow range of 0.17 to 0.21. On an average 3W are observed to be 0.60 to 0.78 times equivalent to cars. Evidently, the field observed values are quite different from PCU values recommended by IRC.

5. EFFECT OF FLOW-RATE ON DVEF

Although there are several factors influencing the DVEF value of a vehicle type, traffic volume and composition are the most important factors for a given roadway, influencing the amount of interaction between vehicles in the traffic stream, and hence the DVEF values for the different types of vehicles. Here, variation of the DVEF values with respect to the traffic flow rates for every 5-minute interval is analysed. The variation of DVEF, values for 3W and 4W with respect to flow rate (vehicles per hour: vph) is shown in figure 1. The general trend observed for both vehicle types shows increase in DVEF value till the flow rate to 3000 vph. Beyond this flow rate level there is pinkuction in DVEF, value up to flow rate of 6000 vph level and becomes constant for flow rate higher than that. The trends of DVEF follow the variation of speed ratio with flow rate for both the vehicle types.
Figure 1  Variation of DVEF, with flow-rate

Figure 2 shows variation in DVEF<sub>c</sub> value for 2W and 3W with flow rate. The DVEF<sub>c</sub> value for 3W increases sharply with flow rate up to 4000vph level and later on slowly decreases.

Figure 2 Variation of DVEF<sub>c</sub> with flow-rate

The DVEF<sub>c</sub> value for 2W is observed to vary marginally with increase in flow rate. This is due to the fact that speed ratio for 2W varies in the narrow range 1.04 to 1.27. It can be observed that effect of dominance of 2W in traffic stream is significant compared to car, constituting only 20% of total traffic in the stream.

6. TRAFFIC FLOW MODELS

Traffic flow behavior is quantified through relationship between speed-density, speed-flow and flow-density in macroscopic approach. As density increases, speed decreases. At midpoint of speed-density curve, the flow condition changes. Two distinct situations are established; namely
one related to free-flow condition and other related to congested or forced flow condition. The capacity of a road is defined by the apex point of speed-flow curve where transition takes place from free-flow condition to congested flow condition. Highway Capacity Manual (HCM) has used this concept to define capacity and also the concept of Level-of-Service (LOS) to characterize the different operating conditions on a road type. These have, however, been established for free-flow condition only. In the present study, observed free flow data of density, speed and flow is plotted in excel worksheet. Models are developed considering traffic characteristics of flow rate and density in terms of vehicles, static PCU, DTU and DCU. Variations in the capacity and related density values are observed in the Flow (Q)-Density (K) – Speed (V) models derived in the different vehicle equivalent units. Optimal (critical) density is derived by differentiating flow(Q) – density (K) models with respect to density (K) and equating to zero for maximum flow rate or capacity condition. Capacity is calculated by placing value of critical density in the flow-density model whereas jam density is calculated by placing flow rate as zero in this model. Free flow condition prevails when density is less than critical density.

6.1 Traffic Flow Models in Vehicle Units

Figure 3 shows the data points of density in veh./km and flow rate in veh/h in blue colour for free flow regime, whereas congested flow regime data is shown in pink colour. Quadratic equation is derived by the curve fitting through the observed data sets and shown in the figure. The values for congested flow regime shown in pink colour in the figure are found by placing the density values beyond maximum flow in the equation.

$$Q = -0.060K^2 + 39.47K + 414.3$$

$$R^2 = 0.977$$

It can be observed that the coefficient of determination for the model is 0.977 which shows that the traffic flow behaviour is explained almost fully by the model. The speed(V) – density (K) relationship is plotted from the observed data as shown in figure 4. The observed data is found to form two clusters; one between density range of 20–100 veh/km and other between 120–220 veh/km. Data for density and speed for congested flow regime are derived by using flow – density model and are plotted. The two distinct flow regimes are observed to prevail when the congested regime data is combined with the second cluster of observed speed – density data.
Models derived for these two regimes are linear in nature with very good co-efficient of determination. Free flow regime model gives free flow speed for the stream as 50 kmph. Congested regime model gives jammed density value of 663 veh./km which matches with that given by density – flow model. From the observed data, curve is plotted between speed and flow rate (vph) as shown in figure 5.

\[ V = -0.063K + 42.155 \]
\[ R^2 = 0.989 \]

\[ V = -0.108K + 49.83 \]
\[ R^2 = 0.788 \]

![Figure 4 Speed-Density curve (vehicle units)](image)

![Figure 5 Speed-Flow curve (vehicles)](image)

The speed – flow data for the forced flow condition is derived by using flow- density and speed – density models. Quadratic equation for speed – flow relation is derived by the curve fitting through the observed data sets as shown in figure 5. Free flow speed value of 53 km/hr can be obtained from this model. This model is valid up to the capacity level.

6.2 Traffic Flow Models in Static Passenger Car Units
The flow – denisty model in terms of the static PCU values is derived by plotting the observed data of density (SPCU/km) and flow rate (SPCU/h). The second order polynomial model is developed using curve fitting technique and is shown in figure 6. It can be observed that the co-efficient of determination for the model is 0.965 which shows that the traffic flow behaviour in terms of SPCU is explained effectively by the model.

\[
Q = -0.082K^2 + 42.45K + 356.7 \\
R^2 = 0.965
\]

Data for density and speed for the forced flow regime are derived by using respective flow – density model. The two distinct flow regimes are observed to prevail when the congested regime data is combined with the second cluster of observed speed – density data as shown in figure 7.

\[
V = -0.124K + 51.19 \\
R^2 = 0.792
\]

\[
V = -0.085K + 44.92 \\
R^2 = 0.993
\]

Models derived for these two regimes are linear in nature with very good co-efficient of determination. The free flow speed for the stream from the model is 51kmph which closely matches with the field observed free flow stream speed. Figure 8 shows speed-flow behaviour through data points for the free flow in blue colour and forced flow in pink colour in terms of SPCU. Mild quadratic equation is derived for the observed free flow regime to explain the traffic
flow behaviour. The free speed for the stream is measured as 50 km/hr from the speed – flow curve. It is desirable to have detailed study during very low density traffic conditions when vehicles can travel at the speed as per driver’s choice for realistic value of the free flow speed. Quadratic equation for speed – flow relation is derived by the curve fitting through the observed data sets as shown in figure 8.

\[ V = -5E-07Q^2 - 0.001Q + 49.67 \]
\[ R^2 = 0.660 \]

![Figure 8 Speed-Flow curve (static pcu)](image)

Free flow speed value of 50 km/hr can be obtained from this model. This model is also valid up to the capacity level.

### 6.3 Traffic Flow Models in Dynamic Two Wheeler Units

The behaviour of stream flow and density in terms of the dynamic two wheeler units (DTU) is derived by plotting the observed data of density (DTU/km) and flow rate (DTU/h). The plotted values, the fitted curve and the quadratic equation are shown in figure 9.

\[ Q = -0.051K^2 + 52.51K - 103.7 \]
\[ R^2 = 0.941 \]

![Figure 9 Flow-Density curve (DTU)](image)
It can be observed that the model has very high co-efficient of determination of 0.941. This indicates that the traffic flow behaviour in terms of DTU is satisfactorily represented by the model. The speed – density relationship is shown in figure 10. The blue colour points are the observed data points whereas pink colour points are the data derived by using flow – density model. Interestingly, there is no distinction in the trends of the observed data for free flow regime and the congested flow regime. The free flow speed of 51 kmph is given by the model.

\[ V = -0.047K + 51.21 \]
\[ R^2 = 0.688 \]

Figure 10 Speed-Density curve (DTU)

The speed-flow behaviour in terms of dynamic two – wheeler units is depicted through data points for the free flow (in blue colour) and forced flow (pink colour) is shown in figure 11. It may be observed that the data follows non – linear trend for the observed free flow regime. The

\[ V = -2E-07K^2 + 0.0017K + 40.425 \]
\[ R^2 = 0.486 \]

Figure 11 Speed-Flow curve (DTU)
relatively lower co-efficient of determination shows further scope of improvement of the model. Free flow speed value of 41 km/hr can be obtained from this model. This model is valid up to the capacity level

6.4 Traffic Flow Models in Dynamic Car Units
The behaviour of stream flow and density in terms of the dynamic car equivalent units (DCU) is studied by plotting the observed data of density (DCU/km) and flow rate (DCU/h) (Figure 12).

\[
Q = -0.153K^2 + 42.59K + 154.1
\]
\[
R^2 = 0.972
\]

![Figure 12 Flow-Density curve (DCU)](image)

The values derived from observed stream characteristics are shown in blue colour data points where as the pink colour data points are obtained by extrapolation of the fitted quadratic model for the observed data. \(R^2\) value of 0.972 for the model indicates satisfactory presentation of traffic stream density and flow behaviour for the road section in terms of dynamic car units. Speed – density behaviour in terms of dynamic car units is depicted in figure 13.

\[
V = -0.225K + 50.21
\]
\[
R^2 = 0.779
\]

\[
V = -0.159K + 44.6
\]
\[
R^2 = 0.992
\]

![Figure 13 Speed-Density curve (DCU)](image)
Data for density and speed for the forced flow regime are derived by using flow – density model. Two distinct flow regimes are observed when the congested regime data is combined with the second cluster of observed speed – density data. Models derived for these two regimes are linear in nature and have very good co-efficient of determination. The speed – density model gives free speed for the stream as $V_s = 50$ kmph. Finally, the speed – flow relationship for the Gaurav Path is analysed by plotting flow and speed data in terms of dynamic car units as shown in figure 14.

![Figure 14 Speed-Flow curve (DCU)](image)

The free flow regime data points are shown by blue colour. Free speed value of 49 km/hr can be obtained from this model. This model is valid up to the capacity level.

7. TRAFFIC FLOW MODEL PARAMETERS

The traffic flow models for flow – density and speed – flow are of quadratic form and are observed to represent the relationship of stream flow variables in excellent manner for the free flow regime. These models are used for extrapolation to reflect on the forced flow regime. The important parameters like capacity, optimal density, speed at capacity and jammed density are derived in various equivalent units using these models.

Speed – density behaviour study indicates prevalence of two flow regimes within the free flow conditions. The models developed in terms of vehicle unit and PCU are able to distinguish these two sub – regimes. The explanatory power of speed – flow models for the free flow conditions is observed to be quite satisfactory in un–congested flow regime. Stream flow behaviour parameters of capacity, critical density, jam density and speed at maximum flow derived by the models for the selected access controlled arterial are given below in table 2.
Table 2 Comparative traffic stream flow characteristics

<table>
<thead>
<tr>
<th>Equivalent vehicle</th>
<th>Capacity ($Q_{max}$) (flow/h)</th>
<th>Speed at capacity ($V_c$) (km/h)</th>
<th>Optimal Density ($K_o$) (veh/km)</th>
<th>Jam Density ($K_j$) (veh/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>6905</td>
<td>21</td>
<td>326</td>
<td>663</td>
</tr>
<tr>
<td>Static PCU</td>
<td>5852</td>
<td>23</td>
<td>259</td>
<td>526</td>
</tr>
<tr>
<td>IRC (PCU)*</td>
<td>5142</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>DTU</td>
<td>13414</td>
<td>26</td>
<td>515</td>
<td>1028</td>
</tr>
<tr>
<td>DCU</td>
<td>3097</td>
<td>22</td>
<td>138</td>
<td>280</td>
</tr>
</tbody>
</table>

* Derived based on design service volume for level of service C.

The comparison of capacity derived based on recommendations of IRC:106 – 1990 with those obtained from the models show considerable difference. This can be attributed to the fact that a constant (static) value of PCU, irrespective of traffic volume, is considered for 2W (0.75) and 3W (2.0) by IRC, whereas, in present study, values of PCU are derived dynamically for varying traffic volume to account for variations in vehicle interactions and resultant speed differentials. Also, ratio of capacity in DTU and DCU shows that the average PCU for 2W is 0.23 as against 0.75 as specified by IRC.

8. CONCLUSION

The heterogeneity of traffic observed on the urban roads in India with predominance of two wheelers on one side and absence of any lane discipline by the vehicles moving in the stream on the other renders the stream flow behaviour very complex and peculiar unlike the homogeneous traffic condition prevailing in developed countries. The study is carried out to analyse the traffic characteristics and flow behaviour on the mid block section of the access controlled arterial road in Surat city in India. Dynamic vehicle equivalent factors developed using homogenisation coefficient method considering two wheeler and four wheeler as reference vehicles are found to vary as the flow rate changes. The values of dynamic PCU ($DVEF_c$) are much less compared to those recommended by IRC. It is desirable to express mix traffic in terms of dynamic two wheeler units due to significant variation in equivalent factors for 3W and car with traffic volume when expressed in DTU.

Speed – flow – density models developed in the study are able to represent the traffic flow behaviour under heterogeneous environment quite accurately in free flow conditions. Flow – density and speed – flow models are of quadratic form, where as speed – density models are represented by linear equations. DCU based models are significantly differing from Static PCU based models resulting into lower capacity and other flow parameters. Rather the static PCU over estimates effect of 2W and 3W in arterial traffic stream when 2W are predominant. Two distinct sub regimes are depicted in speed – density models in free flow and near capacity regions when the density is expressed in terms of veh / km and SPCU / km. Further probing is
needed to establish thresholds of these sub-regimes. The models can be applied to assess the essential traffic flow characteristics like speed and volume for similar type of road where identical composition prevails. The models can also be used to establish levels of service to reflect on the quality of service offered by the urban transport corridor of similar nature. Traffic and transport planners, in turn, can effectively carry out planning and designing of urban road system as well as traffic control and regulation measures.

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REFERENCES


IRC: 106 (1990) Guidelines for Capacity of Urban Roads in Plain Areas (First revision), Indian Roads Congress, New Delhi.