

## **A concept of Platoon Flow Duration in Data Aggregation for Urban Road Capacity Estimation**

Gunasekaran K., Kalaanidhi S., Gayathri H. and Velmurugan S.

### **Abstract**

On urban roads, vehicles traverse the sections as platoons mainly due to the upstream intersection control. The flow on urban road sections is not continuous and the capacity of it depends the duration that is permitted and the interactions among the vehicles travelling as platoon. This study introduces the concept of identifying platoon flow period based on Minimum Free Headway (MFH) and aggregation of traffic data using the platoon flow period. The traffic flow on the section of a six lane divided urban road in Chennai city was recorded using videography from an elevated location and analyzed. Capacity of the selected study road was analysed with traffic flow rate estimated for fixed time intervals (1 minute, 5 minutes, 10 minutes, and 15 minutes) and platoon flow period and the results are discussed in this paper. It was found that the estimation of capacity using flow rate computed for platoon flow period represents the traffic scenario in a better way than that estimated with fixed time intervals.

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## 1. Introduction

The urban traffic flow is often interrupted by the presence of signalised intersections. The difference between rural and urban roads is due to the type of control at upstream intersection and the distance between upstream and downstream intersections (HCM, 1965, HCM, 2000). If, for an urban road, the spacing between the signalized intersections is more than 2 miles, then the impact of the signal might be nullified and the section should be analysed as a rural road section (HCM, 2010).

Because of the interruptions, the vehicles tend to move as groups, i.e., called as platoons. HCM defines platoon as “a group of vehicles traveling together either voluntarily or involuntarily because of signals control, geometrics, or other factors” (HCM, 2000). Even though, there is no clear guideline to quantitatively measure “platoons” in a traffic stream. The HCM definition of platoons fails to explain clearly the term “traveling together as a group” to determine the platooned vehicles in a traffic stream (Al Kaisy and Durbin, 2011).

Various studies (Gaur and Mirchandani, 2001; Jiang et al, 2002; Tanaka and Uno, 2013; Karim et al, 2014) attempted to define the platoon as group of two or more vehicles moving along. However, there is no detail on how close the vehicles must be, either by space or time, in order to consider as platoon. Platoon formation, particularly in heterogeneous traffic situations may be due to many factors other than interruptions due to signals, such as composition of different vehicle types, significantly different acceleration and deceleration characteristics of vehicles, and proportion of slow moving vehicles in the traffic stream.

The flow rate estimated by aggregating the flow in fixed intervals, 5 minutes or 15 minutes periods is likely to fail in depicting the observed flow. In case of fixed time signal control, the number of vehicles permitted into the section depends on the duration of green intervals. The flow allowed into the section varies with the green period and the vehicles enter the section as platoons. The vehicles traverse the section in platoons up to next intersection if the distance is less than 2 miles (HCM 2010). If between two successive green intervals a red interval exists, the stretch is likely to have no flow. The period of no flow in a stretch may vary from 25% to 50%. Estimating flow rate for fixed time periods like 5 minutes or 15 minutes would not be a true representation of traffic flow whereas if the estimation based on the time by the platoon to cross a location would be a better representation of observed flow. Hence an attempt has been made to estimate flow rate based on platoon flow period, relate it with the corresponding stream speed and establish the capacity of urban roads.

## 2. Study background

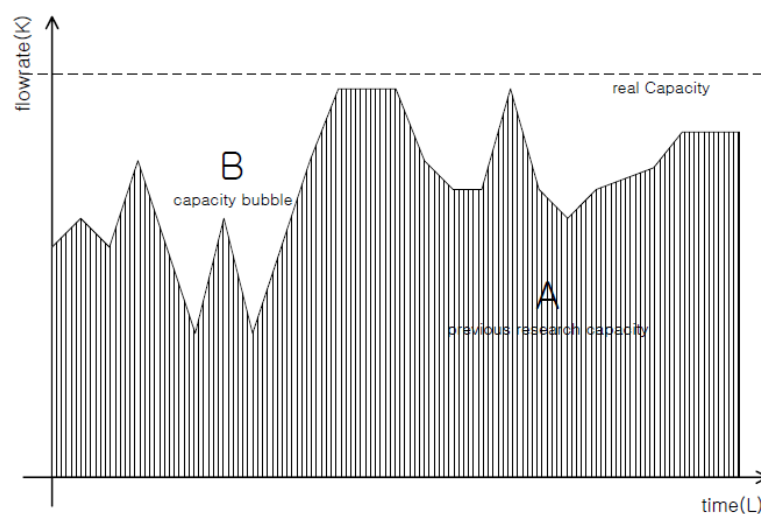
Many methods have been suggested for estimation of urban road capacity. PIARC (2001) suggested the use of field observations of traffic flow for capacity estimation. It was suggested that theoretical capacity of any road section is to be calculated by measuring the maximum volume in fifteen minute interval and reducing by Peak Hour Factor (PHF). Even though the volume might not be the absolute figure, it is assumed to represent reasonable repeatability. On Indian roads, lane discipline is not practiced and so Arasan et al (2008) suggested estimating capacity for total width as the vehicles move laterally across the road width.

As flow on Indian roads is heterogeneous, estimation of PCE values is essential. Chandra S (2008) proposed a methodology to estimate PCE values for mixed traffic conditions. He estimated the PCE values as a function of the vehicle area and speed. Vehicle area is taken as their respective projected rectangular areas (length \* width) i.e., space occupied on road. This method is widely adopted and accepted in India. Tiwari et al (2007) suggested that modified density method can be used for heterogeneous traffic. By modified density method, PCE for subject vehicle is calculated by dividing the ratio of density to base width of passenger car by that of subject vehicle.

The use of headway for capacity estimation has been introduced by many researches. Theoretical capacity of a road is identified as the ratio between 3600 and the average headway of traffic (May A. D., 1990). However, average headway may not precisely represent the traffic flow characteristics. Considering the formation of platoons, the headway distribution was analysed for the capacity estimation (Li et al., 2011; Chang and Kim, 2006). An attempt was made by Chang and Kim (2006), to consider headway of vehicles for capacity estimation. The study detailed the statistical techniques used to determine the best confidence level to represent the capacity of traffic. Different values of capacity of traffic were obtained for each confidence headway interval. Li et al (2011) conducted a study to estimate capacity using headway distribution. Traffic data at arterial roads in Beijing were collected. The authors have found out the distribution pattern of headways of vehicles for arterial roads. The study concluded that Gamma distribution was the best fit of the headway distribution of vehicles on urban arterials in Beijing. A relationship between headway distribution and the road capacity was also developed.

The capacity value for urban roads suggested by the versions of HCM has increased (Zunhwan et al, 2005). A detailed investigation was attempted by Zunhwan et al. (2005) to identify the reasons for revision in capacity values. The study concluded that the rough estimation of capacity using 15

minutes base traffic data as one of the reasons for the inconsistency. The study also proposed a new methodology for the estimation of capacity, i.e., Dynamic Highway Capacity Estimation (DHCE) in an attempt to overcome the shortcomings of HCM. The study explains the shortcoming with the conventional practice by demonstrating the existence of capacity bubbles (Figure 1) which is termed as arrival impedance. But the DHCE suggests different capacity values for different traffic flows which may be the limitation of their work.



**Fig. 1.** Real capacity and capacity bubble

### 3. Methodology

Vehicles travel in groups i.e., in platoons on urban roads. The speed of a vehicle is influenced by the lead gap available in the front and the variation in the lead gap is the crucial factor for acceleration or deceleration. That is, the headway between vehicles influences the vehicular speed. If the vehicles travel in platoon with the intra vehicular headway less than the free flow state and their speed are largely influenced by the presence of the vehicles in the front. If the headway is greater than minimum free flow headway, the speed of the vehicles depends on the driver and vehicular characteristics.

For ease of estimation, the flow rate is computed taking fixed intervals i.e., 1 minute or 5 minutes, or 10 minutes or 15 minutes. Large time inter-

vals, like 5 minutes or 15 minutes, are usually adopted to estimate the flow rate. Considering fixed time intervals to compute the flow rate is likely to include periods of no flow.

Consider three sections of urban road as shown in figure 2. In each section, the time intervals taken for the flow to leave the section is marked as t. In section I, the number of vehicles, n1=11 and as the flow requires 25 seconds to leave the section the average headway is 2.27 seconds. For section II, n2=6, t2=10 seconds and average headway is 1.57 seconds. Similarly, for section III, n3=3, t3=15 seconds and average headway is 1.67 seconds. If fixed time of 25 seconds is taken for flow rate estimation and average headway h' is calculated as inverse of flow rate the h1'=2.27 seconds, h2'=4.16 seconds and h3'=8.3 seconds.

The flow rate and stream speed computed for section I by fixed time interval and actual duration would match for section II and section III if flow period is less than fixed time interval considered the computed flow rate value would not truly represent the field condition. The platoon flow period and number of vehicles in the platoon are used to compute the flow rate (eqn.1) in PCEs and the stream speed is computed as the harmonic mean of vehicles expected in the platoon flow period.

$$(\text{Flow Rate})_i = \{(\text{No. of Vehicles in the Platoon})_i * 3600\} / (\text{Platoon Flow period} + \text{minimum free headway})_i \quad (1)$$

The speed-density flow rate and stream speed plots was analysed for the data aggregated for fixed time intervals and platoon flow period.

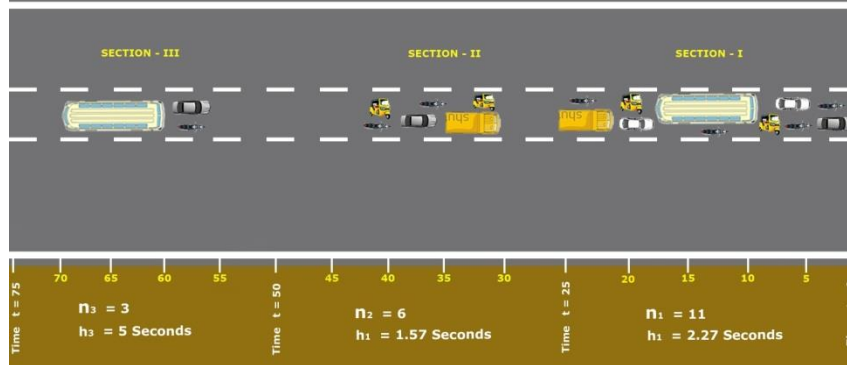


Fig. 2. Illustration of Flow as Platoons on Urban Roads

With the plot of average stream speed and headway at which the average speed declines is considered as the minimum free headway beyond which the vehicles are outside the influence of platoons (Al kaisy A and Durbin C, 2011). The number of vehicles moving as platoon was deter-

mined as those vehicles with headway less than minimum free headway. The advantage of this proposed methodology is demonstrated in this study by plotting headway against average speed of the traffic stream aggregated for fixed time intervals and MFH.

#### 4. Study Section

A major arterial road in southern part of Chennai city, Rajiv Gandhi Road, was chosen for the study. It is a six lane divided carriageway. Service lanes were provided on both the directions and the access from the service lanes to carriageway is restricted and hence the side friction to the traffic flow on the road is avoided. The traffic flow from Madhya Kailash intersection to Tidel Park intersection was considered for this study. The section length was 2.2 Km. The count of the vehicles, speed of the vehicles and time of arrival was obtained from video records. The videography was carried at a location about one kilometer from the Madhya Kailash intersection (Figure 3).

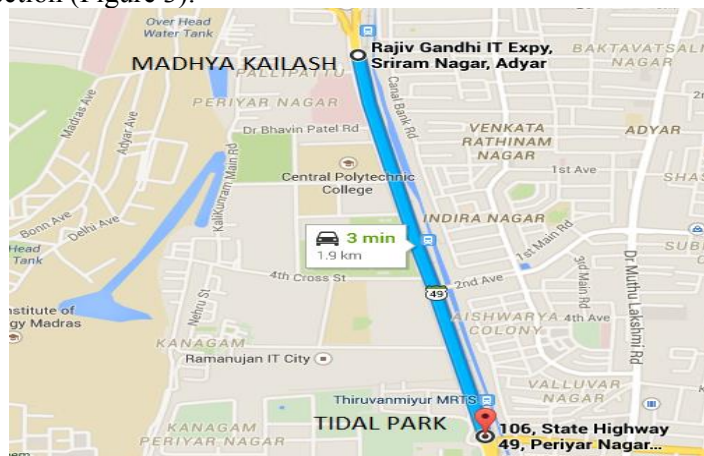


Fig. 3. Location of Rajiv Gandhi road

#### 5. Data Collection & Retrieval

The trap section was marked in the video with solid lines joining the adhesive tapes with the help of multimedia software. The time taken by the vehicles to enter and leave the 60 meter demarcated trap section was entered with the aid of software developed. Classified Volume Count and

Speed of the vehicles were extracted from the video records using an application developed for video data extraction on C# platform. The video was run repeatedly to extract the time of entry and exit for all type of vehicles and on all the three lanes.



Fig. 4. Camera setup at location and snapshot of video recording

### 6. Traffic Characteristics

The traffic flow varied between 3050 and 3890 vehicles per hour. Maximum flow of 1894 vehicles per hour was observed on the middle lane. The flow on far side lane (lane closer to median) varied between 735 and 1005 vehicles per hour. Similarly, the flow on middle lane varied between 1479 and 1894 vehicles per hour and on near side lane (lane closer to shoulder) it varied between 844 and 995 vehicles per hour. Figure 5 shows the hourly variation of traffic flow over different lanes.

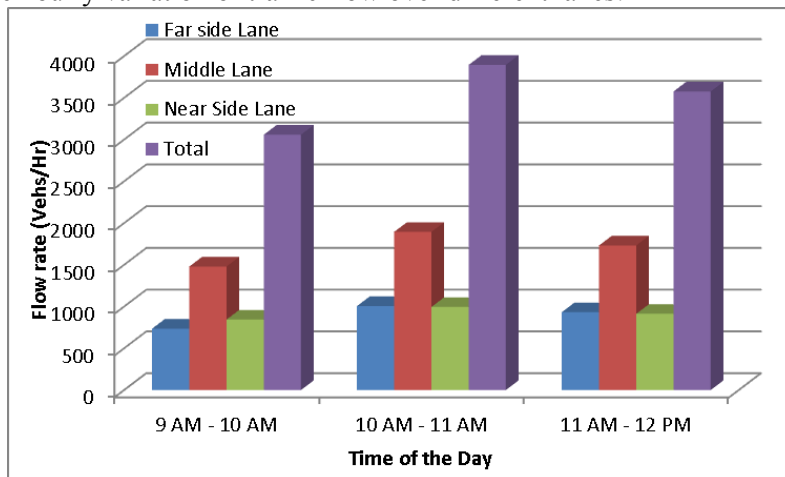


Fig. 5. Hourly Volume observed at Rajiv Gandhi road

On the study section 57 % vehicles were two wheelers and 33 % were cars. Three wheeler auto rickshaws were about 5 % of the total traffic flow, the share of buses was nearly 1% and the other categories of the vehicles contributed to the remaining 4 % of total traffic. The composition of vehicles on the road is shown in Figure 6. PCE values of each vehicles category was computed based on the method suggested by Satish Chandra (2008) and was used to express the flow in PCEs. The extracted speed data were found to be distributed normally with the mean speed of 46.41 Km/h and standard deviation of 9.57 Km/h. The distribution of vehicle speed is shown in Figure 7.

A plot of number of vehicle arrivals per ten second duration was performed (Figure 8). The flow is pulsating and it was due to the signal control at the upstream intersection (Madhya Kailash intersection). It is evident that flow on urban roads is not continuous as on rural roads and due to red intervals at upstream intersection no flow is observed on the section for certain time intervals. So, for estimation of flow rate, the period of observed flow needs to be taken for urban roads. If fixed time intervals are taken for flow rate calculation, it would be a misrepresentation of the condition existing.

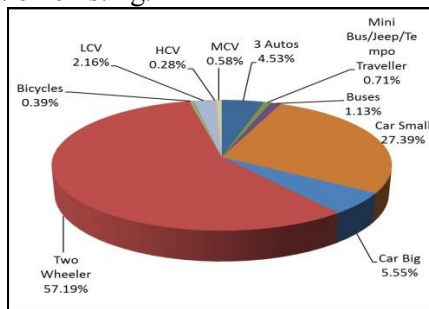


Fig. 6. Composition of vehicles on Rajiv Gandhi road

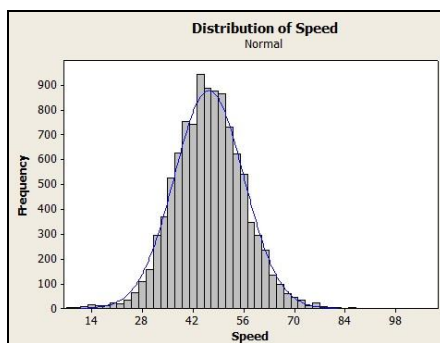
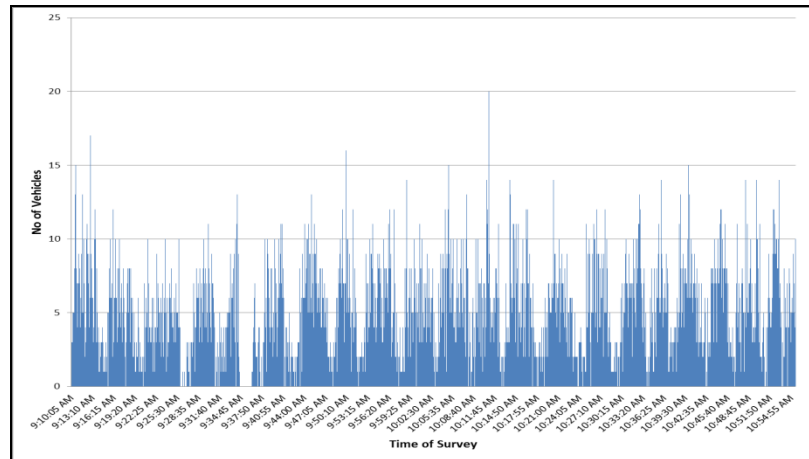


Fig. 7. Distribution profile of speed of vehicles on Rajiv Gandhi road





**Fig. 8.** Vehicle arrival pattern on Rajiv Gandhi road

The platoon flow duration is the duration between time of entry of the platoon leader and the last vehicle in the platoon. The number of vehicles in the platoon and platoon duration is required for estimating the flow rate. The space mean speed of the group of vehicles in platoon would be stream speed of the corresponding platoon. The plot of flow rate and stream speed could be used to estimate the capacity of the urban road section.

## 7. Identification of Platoons

Platoon is the group of vehicles in congested and intermediate state i.e., the speed of the vehicles is influenced by vehicles in the front. Minimum Free Headway (MFH) is the headway used to define the platoon as the vehicle having headway lesser than this value will be considered as part of platoon. In other way, the vehicles having headway greater than MFH will be considered as not part of the platoons. Chandra (2001) reported that state of flow could be identified by semi log plot of lower limit of class interval of time range and percentage of headway greater than lower limit of class interval. From the plot the different traffic states viz., congested state, intermediate/transition state and free flow state could be identified. The plot is shown in Figure 9. The Minimum Free Headway for the study stretch is 7.0 seconds. Some part of the flow on urban roads is also in free state.

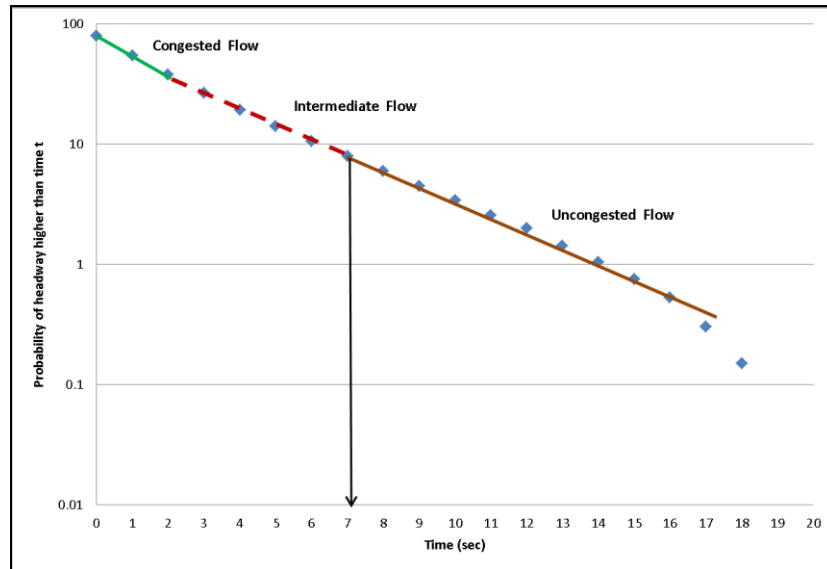


Fig. 9. Headway distribution at Rajiv Gandhi road

## 8. Estimation of Passenger Car Equivalents

Traffic flow in heterogeneous traffic conditions is expressed in Passenger Car Equivalents (PCEs). The PCE values of vehicles are obtained by comparing the vehicle's plan area and speed with that of passenger car. The PCE values for various vehicles are not constant and it is found to vary as the speed of the vehicle vary with the prevailing traffic and road conditions. The constant PCE values recommended in Indian Roads Congress Guidelines 106 (IRC 106, 1990) is reported to have limitations. On review of the existing methods of PCE estimation, the concept of Dynamic PCE was introduced (Chandra et. al, 1995) and proposed by Satish Chandra (2008). The PCE values for the vehicles are estimated for different volume ranges. The idea is that the speeds of the vehicles are not same in all volume ranges and hence the PCE values also vary according to the volume ranges. The method for estimating PCE value suggested by Satish Chandra is given in Eqn. 2.

$$PCE_i = (V_c/V_i) / (A_c/A_i) \quad (2)$$

Where,

$V_c$  = Speed of the Car,

$V_i$  = Speed of the subject Vehicle

$A_c$  = Plan Area of the Car

$A_i$  = Plan Area of the subject Vehicle

That is used of fixed periods for flow rate estimation considered the flow on urban roads as mostly in congested and intermediate state whereas the use of Platoon Flow Period in flow rate estimation described the flow on urban roads to be also partly in free flow state. Using the above method, the PCE values for all categories of vehicles were estimated for the data collected and is given in Table 1.

**Table 1.** Estimated Dynamic PCE values for various Aggregation Periods

PCE values for various Aggregation Periods					
Vehicle Types	1 Min	5 Min	10 Min	15 Min	Platoon Flow Period
Three Wheeler Auto Rickshaw	0.82 - 1.66	1.03 - 1.48	1.07 - 1.25	1.05 - 1.22	0.73 - 1.87
Four Wheeler Auto Rickshaw	1.25 - 1.64	1.31 - 1.72	1.35 - 1.69	1.31 - 1.65	1.15 - 1.76
Mini Bus/Jeep/Tempo Traveller	1.76 - 3.69	1.76 - 3.54	1.9 - 3.04	2 - 3.41	1.85 - 3.43
Buses	3.63 - 6.57	3.47 - 7.03	4.17 - 6.02	4.5 - 6.06	3.56 - 6.56
Car Small	1	1	1	1	1
Car Big	0.57 - 2.04	1.15 - 1.65	1.29 - 1.59	1.34 - 1.57	0.98 - 2.22
Two wheeler (Motorcycle)	0.15 - 0.32	0.18 - 0.27	0.22 - 0.26	0.22 - 0.26	0.11 - 0.52
Bicycles	0.37 - 0.97	0.34 - 0.92	0.32 - 0.67	0.4 - 0.63	0.38 - 0.88
Cycle Rickshaws	1.44 - 4.98	1.47 - 4.31	1.46 - 4.35	1.46 - 4.3	1.42 - 5.35
Light Commercial Vehicles	0.85 - 2.04	0.94 - 1.4	1.05 - 1.32	1.06 - 1.3	0.77 - 2.28
Heavy Commercial Vehicles	2.78 - 5.87	3 - 5.41	3.04 - 4.94	3.15 - 4.96	2.99 - 5.53
Medium Commercial Vehicles	1.75 - 7.21	2.27 - 7.1	2.27 - 6.02	2.36 - 4.57	1.98 - 4

### 9. Comparison of Stream Speed for Data Aggregation Methods

The fixed time interval (1 minute, 5 minutes, 10 minutes and 15 minutes) and platoon flow period were considered for flow rate calculation. As the headway is inverse of flow rate, the plot of average stream headway and average stream speed would help to understand the spacing between vehicles and the stream speed. The average stream speed was plotted against headway using the data aggregated for fixed time intervals and platoon flow period. The graph (Figure 10) shows that the range of headway narrows down if higher fixed time interval is used for flow rate estimation. The plot established for the platoon flow period method of aggregation had a better dispersion over headway (Figure 11).

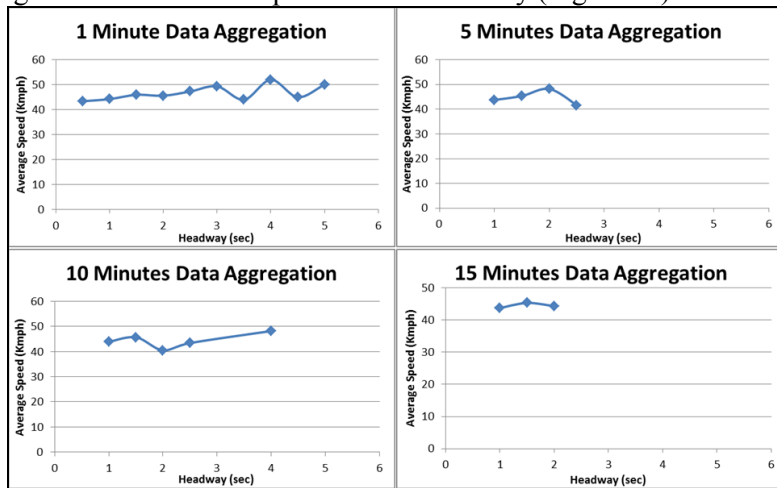


Fig. 10. Average speed – headway plot for various fixed time intervals

The stream speed was computed as harmonic average of the speed of vehicles moving in the duration. The statistical description of stream speed computed by different methods of aggregation is given in Table 2. The average and median speed is almost same for aggregation by fixed time intervals and platoon flow period. The standard deviation and range indicate the spread of speed values is less if data is aggregated for fixed time intervals and the spread is more if aggregated for platoon flow period. The spread of speed data and headway (figure 11) by aggregating by platoon flow period are closer to field measurements and the method of data aggregation is better than by aggregating for fixed time intervals.

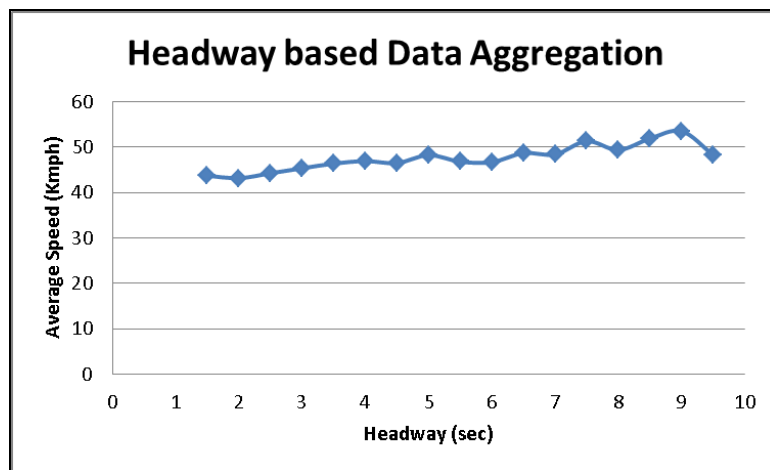


Fig. 11. Average speed – headway plot of headway based time intervals

Table 2. Description of Speed Data in various Data Aggregations

Statistical Parameter	Stream Speed aggregated for				Platoon Flow Period
	1 minute	5 minutes	10 minutes	15 minutes	
Mean	44.86	44.25	44.31	44.24	46.49
Median	44.50	43.91	43.93	44.04	45.72
Standard Deviation	3.56	2.50	2.30	2.18	6.77
Range	21.00	9.86	7.74	5.23	62.06
Minimum	35.00	39.65	40.48	41.74	17.57
Maximum	56.00	49.50	48.22	46.97	79.64

### 10. Results and Findings

Speed – Density and speed flow relationship for fixed time intervals and platoon flow period was analysed. The capacity values were obtained from plotting Speed – Flow plot considering the relationship to be similar to that proposed by Greenshields (Greenshields B.D., 1935). The capacity values were found to be significantly different for each aggregation period. The

Speed – Density plots for various fixed time interval data aggregation methods are presented in Figure 12.

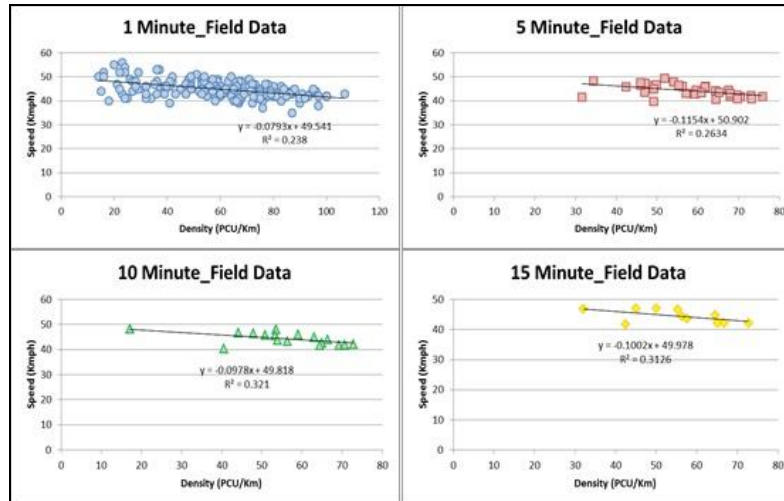


Fig. 12. Speed – density plot of various fixed time intervals

The Speed – Flow curve established using Greenshields method for various fixed time intervals is given in Figure 13. The Speed – Density relationship and Speed – Flow relationship are established for the proposed concept of aggregating data for platoon flow period and shown in figure 14 and figure 15.

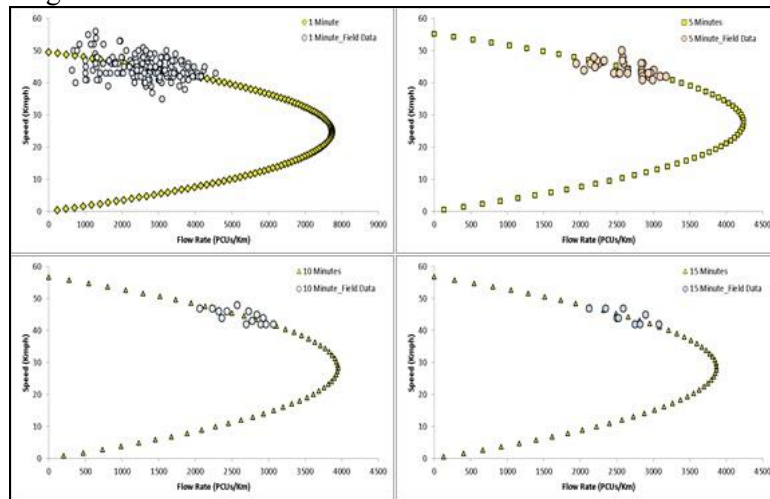
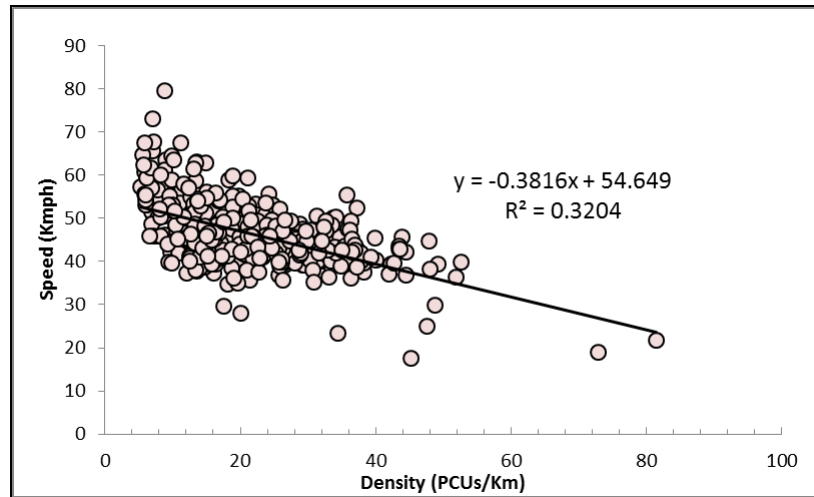
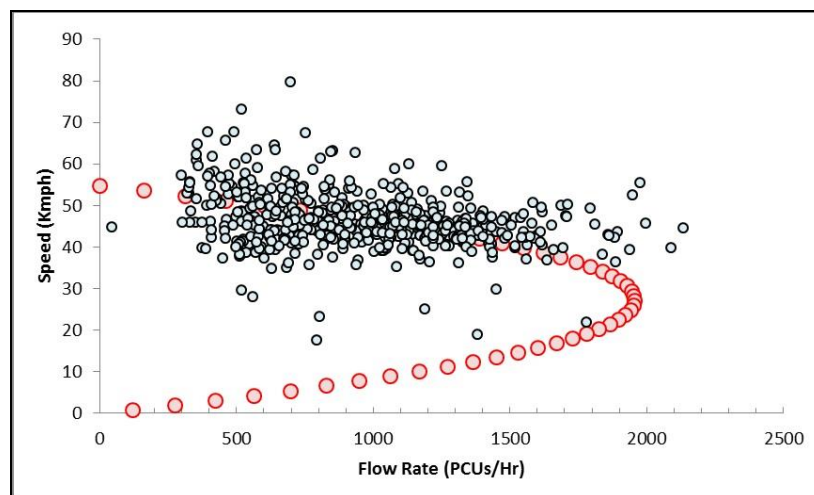


Fig. 13. Speed – flow relationships of various fixed time aggregation based data



**Fig. 14.** Speed – density plot for minimum free headway aggregation based traffic data



**Fig. 15.** Speed – flow plot for minimum free headway aggregation based traffic data

The summary of the traffic characteristics obtained from the above plots is given in table 3. The results obtained through the fixed time analysis reveals that the capacity values of the same road section varies for different aggregation intervals, which is highly undesirable. Data aggregation by

platoon flow period is better to obtain traffic flow parameters and capacity analysis of roads.

**Table 3.** Capacity Values obtained for Different Data Aggregation Intervals

Parameters	Aggregation period				Platoon Flow Period
	1 Minute	5 Minutes	10 Minutes	15 Minutes	
Jam Density in PCE/lane	208	147	170	166	143
$V_f/K_j$	0.08	0.21	0.10	0.10	0.38
FFS in kmph	50	51	50	50	55
Capacity in PCE/hr/lane	2579	1871	2115	2077	1957

## 11. Conclusions

This study examines the shortcoming of conventional practice of fixed time aggregation of traffic data, especially on urban roads. With the traffic data collected from Chennai city, the capacity values obtained for different fixed time intervals were reported in this paper. The reasons for wider differences (1871 PCEs/Hour/Lane to 2579 PCEs/Hour/Lane) in the capacity values with respect to the aggregation interval were discussed. Also, the suggestion for determination of and data aggregation based on platoon flow duration and its significance were demonstrated through this research study. It is conventional practice in traffic flow studies that the traffic data is aggregated for fixed time intervals (1 minute, 5 minutes, 10 minutes, and 15 minutes). It was observed from this study that the flow rate, headway and stream speed data computed for fixed time intervals were closer to the median value and the spread of data was limited. This is contrary to that observed on field and there is a possibility of error in calculation of capacity. For shorter fixed time interval, the spread was better but jam density and capacity values were high whereas for higher fixed time intervals the spread was narrow but the jam density and capacity values were realistic. In other hand, for the data aggregated using platoon flow period, the spread of data was better and the jam density and capacity values were also realistic. With the deployment of sensors to measure the category-wise flow, headway between vehicles and speed precisely, identification of platoons and calculation of traffic flow parameter for platoon flow period is possible.



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