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Studying Platoon Dispersion Characteristics Under Heterogeneous Traffic In India

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Abstract

Platoons are created by signalized intersections which control travel patterns of vehicles. It is common for platoons to disperse during normal traffic operations. While platoon dispersion has been studied extensively under homogenous and lane disciplined traffic conditions, this characteristic under heterogeneous conditions has not been addressed adequately. This study will be one of the first steps in this direction and will lead to better understanding and simulation of platoon dispersion under Indian conditions.

Data describing platoon dispersion was collected with video recording systems along an arterial in Chennai, India. The Robertson's model parameters calibrated for this data was found to be very different from those obtained in previous studies by other researchers. This could be attributed to the highly heterogeneous traffic existing on Indian roads. Dispersion characteristics were studied by taking each platoon individually. The study will augment the understanding of platoon dispersion by discussing the issue of heterogeneous conditions.

Keywords: Platoons: Dispersion; Signal Timing; Traffic Forecasting

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1. Introduction

Platoon dispersion models are necessary to implement and operate adaptive control algorithms and coordinated signal timing plans. Proper modeling of platoon dispersion will improve the ability to simulate traffic conditions, which could potentially aid in geometric design and traffic control areas.

Platoon dispersion has been extensively studied under homogeneous traffic conditions. The studies analysed the effect of traffic volumes, number of lanes, etc. on the rate of dispersion. However, little to no research has been performed to study platoon dispersion in heterogeneous traffic conditions. Heterogeneous traffic in India is characterised by various classes of vehicles sharing the road space without following lane discipline. This leads to the traffic characteristics to be distinctly different from that of the homogeneous, lane disciplined traffic conditions. Platoon dispersion characteristics also will be different since the different classes of vehicles have different acceleration capabilities acceleration and maximum speed capabilities which affect vehicle movements and interactions. Also, the smaller vehicles percolating through the queues at signals and occupying the front of the queue, leads to the queue discharge characteristics and dispersion to be different from the traditional ones.

Thus, traditional dispersion models may not be suitable or will need calibration to make them suitable for heterogeneous conditions. Proper understanding of platoon dispersion under these conditions is critical to correctly calibrate simulations which are commonly used for design decisions.

Platoon dispersion is traditionally described using Robertson's model with a platoon dispersion factor, α, and a travel time factor, β. Previous research recommends values of α and β for a variety of geometric conditions. However, range of these values that is suitable for a heterogeneous traffic conditions is not addressed so far. In addition to model calibration, analysis will include consideration of characteristic movements for different vehicle types. As heterogeneous conditions have not been well studied, it is possible and likely that non-traditional vehicles travel differently in platoons compared to passenger cars.

1.1. Literature Review

Platoon dispersion models simulate the dispersion of traffic as they move from upstream to downstream. They estimate the downstream flow on the basis of the upstream vehicle departure profile and the average travel time in the link. Lighthill and Witham (1955) used the kinetic wave theory to study the dispersion. Pacey (1956) used the diffusion theory to characterize dispersion, where he assumed that if the stream speeds are normally distributed, the dispersion in the corresponding platoons can be described by the dispersion in speeds. Robertson (1969) developed an empirical platoon dispersion model using a discrete iterative technique. Because of the simplicity in applying the model, it gained popularity and became a virtual standard platoon dispersion model. Robertson's model is given by:

$$q_t^d = F * q_{t-T} + (1 - F) * q_{t-n}^d \quad (1)$$

where, q^d_t is the arrival flow rate at the downstream signal at time t, q_{t-T} is the departure flow rate at the upstream signal at time (t-T), T is the minimum travel time on the link (measured in terms of unit steps $T = \beta T_a$), T_a is the average link travel time, F is the smoothing factor given by

$$F = \frac{1}{1 + \alpha\beta T_a} \quad (2)$$

with α being the platoon dispersion factor, and β the travel time factor.

Robertson reported the best fit values of α and β as 0.5 and 0.8 respectively based on his study in West London. He also mentioned that the appropriate values of α and β will depend upon the site factors such as roadway width, parking, gradient and others. Seddon (1972b) investigated Robertson's model, rewrote equation (1) as,

$$q_t^d = \sum_{i=T}^{\infty} F(1-F)^{i-T} * q_{t-i} \tag{3}$$

The model follows a shifted geometric pattern and gives the probability of a vehicle passing the upstream point in (t-i)th interval being observed downstream in the (t)th interval. From the basic properties of geometric distribution, he showed that α and β are related to each other, as β = (1/1+α).

El Reedy and Ashworth (1978) estimated the arrival patterns at downstream using both Pacey's and Robertson's model with different dispersion parameters and reported that they varied considerably from the observed pattern, indicating that a fixed value of the parameters may not hold good for every conditions. Yu and Van Aerde (1995) considered travel time in units of seconds and developed three equations for directly calibrating α, β and the smoothing factor F. Rakha and Farzaneh (2005) demonstrated that, for the method adopted by Yu and Van Aerde (1995), the margin of error increased with the size of time step for the estimated downstream profile. They proposed three enhanced geometric distribution formulations that explicitly account for the time-step size within the modeling process. They also studied the effect of the dispersion parameters on the travel distance and concluded that β is more significant for larger signal spacing distances. Christopher and Darcy (2012) described a methodology for measuring platoon characteristics between adjacent signalized intersections for high – resolution data and suggested that the platoon behavior characteristics might be more sensitive to driver behavior characteristics than to the distance travelled. Bie et al. (2013) conducted a survey in China and pointed out that the number of lanes had an evident impact on the platoon dispersion. Also, the calibrated value for α was beyond the value specified in the TRANSYT manual thus showing that the dispersion factor would be different for different driving conditions.

Overall, it can be seen that almost all of the reported studies are from homogeneous and lane disciplined traffic conditions. Present study will be to calibrate the Robertson's model for heterogeneous and lane less traffic and to study the effect of heterogeneity on the model parameters.

2. Data Collection

2.1. Site Description

The study site identified was a 1.3 km section of an urban arterial in Chennai, India, from the Madhya Kailash intersection to the second Foot over Bridge (FOB) on the Rajiv Gandhi Salai. The Madhya Kailash intersection is a signal controlled T – intersection and the flow coming out from this intersection to the Rajiv Gandhi Salai was analyzed. Figure 1 below shows a schematic sketch of the study site and Figure 2 shows the Google maps image.

Digital video cameras were placed at three control points along the study section viz., Camera 1 at the Madhya Kailash intersection, 2 at the First FOB and 3 at the Second FOB as shown in Figure 2. CAM 2 and 3 were placed at a distance of 290 m and 1290 from CAM 1 respectively. The video cameras recorded the passing times of all the vehicles at the respective control points.

The observations were carried out for five days in May 2013. The video data were collected for a period of two hours during the morning peak. Figure 2 also shows sample pictures from the camera locations.

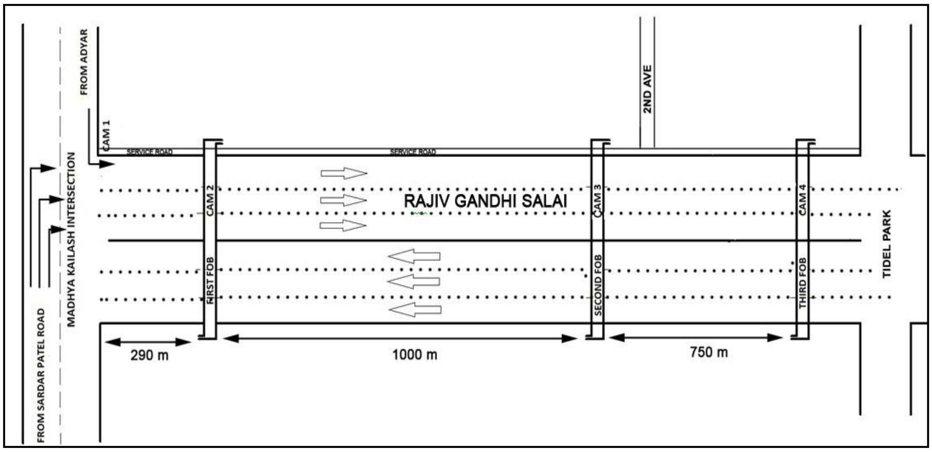

Fig 1. Schematic sketch of Study Site

2.2. Data Extraction and Analysis

The data collected was processed in order to extract the required data on the vehicle passing time at each control point. The vehicles were classified into four classes – Two-wheelers (2W), Three-wheelers (3W), LMV (passenger cars and share autos) and HMV. The extraction was carried out manually by recording a macro in Excel which gave the vehicle class along with the timestamp, as the vehicle passed the point. The timestamp had a least count of millisecond, thus giving more precision. The process was carried out for the 2 hour data from all the three control points. The data reduction for 2 hours took approximately 15 hours, including the noise removal (free left-turn flow from Adyar). Since the data extraction was complex and turned out to be very tedious, it was decided to extract 1 hour data for the rest of the days. Vehicles, as they move from upstream to downstream, disperse to some extent mainly due to the difference in the desired speed of various drivers in the platoon (Yu, 2000). This dispersion was captured by analyzing the same platoons at upstream and downstream points. The main aim of the study is to find the actual dispersion in the site, compare it with the dispersion given by Robertson's model and thus evaluate the model for heterogeneous conditions.

The first FOB was considered as the upstream point and the second FOB as the downstream point. CAM 1 at Madhya Kailash intersection was used to identify the platoons during the cycle time and to remove the free left turns from Adyar side. Around 17 platoons were analyzed and the passing times of all the vehicles in the platoons were noted at both the control points. In addition to this, the start and end vehicle of each platoon was also identified at both the control points in order to distinguish between the platoons. Fig. 3 shows a scatter plot of all the vehicles at upstream and downstream. It can be seen from the plot that the vehicles which move as a platoon from the downstream gets dispersed as they reach the upstream. The average time for the same platoon to move from upstream to downstream was evaluated and was compared with the actual start and end times of the platoon at downstream. This average time was added to the head and tail of the platoon to obtain the mean arrival times at downstream. The head and tail difference was found out as the difference in the times between the actual and mean arrival times. In Fig. 3, '*a*' and '*b*' denotes the difference between the actual and mean arrival times at the head and tail of the platoon respectively.

Fig 2. Google Maps image of the site along with camera locations

To calibrate Robertson’s model, a time step of 10 seconds was taken. The average travel time (T_a) between the two sections was observed to be approximately 60 seconds. The ($\alpha*\beta$) term in equation (2) was treated as a constant, K. For different values of K ranging from 0.001 to 5, the root mean square error (RMSE) for actual flow and estimated flow using Robertson’s model at downstream was determined. The least RMSE obtained was 1.9018 corresponding to K=0.022 or F=0.4310. Figure 4 shows the actual and estimated flows at downstream. It also shows the error (difference in actual count and estimated count) and upstream count shifted by an interval of 60 seconds.

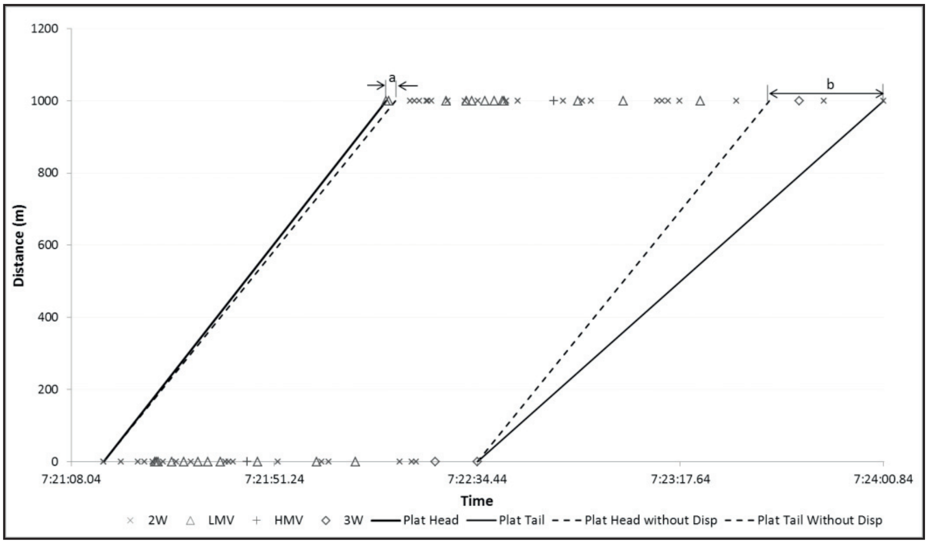

Fig. 3. Dispersion of platoon from upstream to downstream

Using calibrated Robertson’s model, the platoon width at downstream was predicted. It was then compared with actual width of platoon observed at downstream. It was found that, except in the case of one platoon, actual dispersion was more than dispersion predicted by calibrated Robertson's model. 'c' is the deviation of head and/or tail of platoon width(in terms of seconds) predicted by Robertson's model to that of actual width observed at downstream.

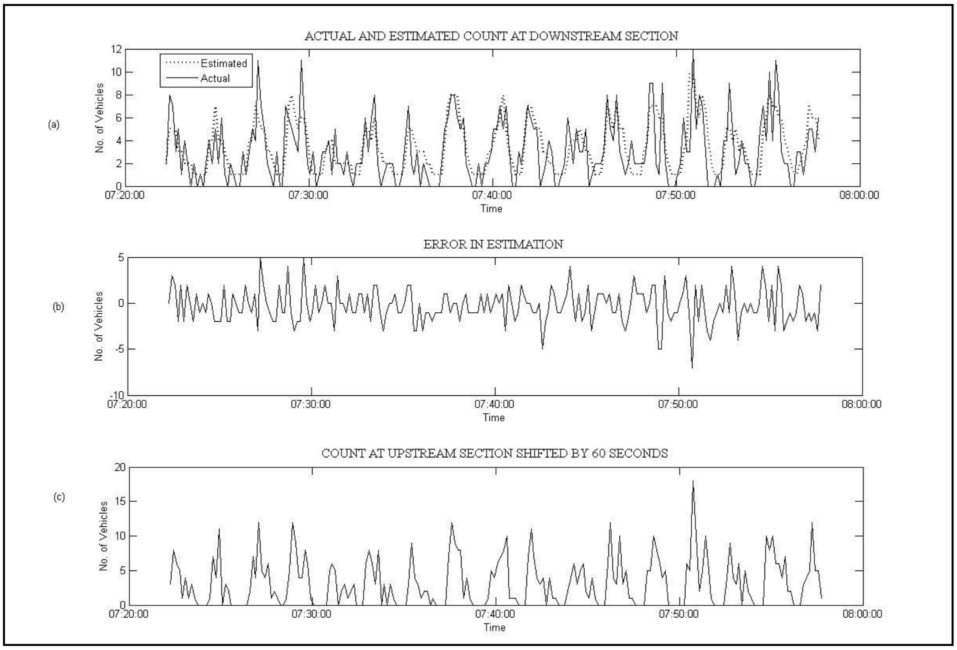

Fig 4. Actual and estimated flows at downstream, actual flows at upstream and error

3. Results

Table 1 gives the platoon characteristics for various platoons, namely their size, vehicle compositions within the platoon and the dispersions in head and tail values. Slope gives the average time interval taken by a platoon to move from upstream to downstream. '*a*' and '*b*' denotes the dispersion in head and tail for each platoons. '*c*' denotes the dispersion obtained from the Robertson's model, which assumes uniform dispersion for head and tail, and hence a single value is given. It can be seen from the table that 2W and LMV constitute a major part of the platoons along with the other vehicles, thus giving rise to heterogeneous traffic conditions. Robertson's model predicts the downstream flow based on the predicted values in the previous step. For platoon 1, the actual downstream value was given as input in the first time step and hence the dispersion was nearly zero.

Fig 3 shows platoon number 1 which comprise of 35 vehicles with 60% being 2W, 34% LMV and rest HMV and 3W. At upstream, the platoon starts with a bunch of 2W but as they reach downstream, they are overtaken by the LMVs which arrive first. This is mainly due to the difference in the desired speed of the various drivers, especially LMVs which accelerate at a much higher rate than the other vehicles within the platoon. Platoon 1 has a head dispersion of 1.68s and a tail dispersion of 24.6s. The high dispersion in tail is mainly due to the presence of some 2W which move at a speed less than the average speed of the platoon. High speeding LMVs increase the average speed of platoon, thus causing more dispersion.

Platoon 6 shows a negative value for the dispersion in tail indicating that more number of vehicles travelled with a speed greater than the average speed of the platoon and thus reaching downstream earlier. It can be seen that platoon 6 has a low composition of LMV's, thereby allowing a lesser average platoon speed and thus enabling all the vehicles to reach the downstream within the average time.

Figure 5 displays a plot of the dispersion for head and tail of the platoons based on the actual values and the same from Robertson's model.

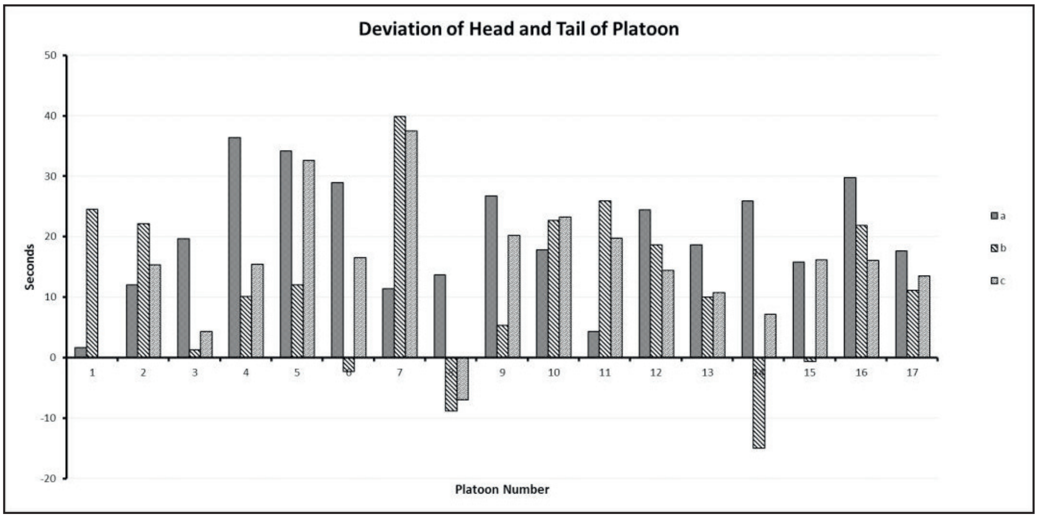

Fig. 5: Dispersion in head & tail from actual & Robertson's Model

Table 1: Dispersion in head and tail for different platoons using actual dispersion and Robertson's model

Platoon No.	Platoon Size	Vehicle Composition (%)				Slope (sec)	Actual Dispersion		Robertsons Model
		2W	3W	LMV	HMV		a (sec)	b (sec)	c (sec)
1	35	60	2.9	34.3	2.9	62	01.68	24.60	0
2	25	40	0	52	8	66	12.03	22.19	15.37
3	44	43.2	4.5	34.1	18.2	67	19.72	1.27	4.36
4	48	47.9	6.3	39.6	6.3	76	36.37	10.13	15.42
5	28	55.2	6.9	34.5	3.4	73	34.22	12.05	32.61
6	36	58.3	8.3	13.9	19.4	72	28.96	-2.26	16.53
7	22	45.5	0	50	4.5	58	11.38	39.93	37.49
8	47	42.6	4.3	46.8	6.4	66	13.72	-8.77	-6.99
9	43	36.4	6.8	43.2	13.6	68	26.78	5.39	20.25
10	40	60	2.5	37.5	0	67	17.86	22.75	23.31
11	35	42.9	5.7	37.1	14.3	61	4.30	25.96	19.75
12	47	53.3	4.4	31.1	11.1	69	24.50	18.69	14.44
13	41	48.8	7.3	31.7	12.2	58	18.66	10.05	10.77
14	51	48	2	42.0	8	65	25.94	-14.92	7.15
15	34	55.9	2.9	29.4	11.8	61	15.83	-0.59	16.22
16	63	41.3	11.1	38.1	9.5	73	29.79	21.89	16.06
17	35	54.3	8.6	28.6	8.6	87	17.65	11.18	13.49

4. Summary and Conclusion

This study was undertaken to evaluate the platoon dispersion for the heterogeneous traffic conditions in India using the standard Robertson's model and the actual dispersion in the site. Successful application of Robertson's model requires an appropriate calibration of its parameters, which is still an open question in the literature. Robertson predicted a best fit value of 0.4 for 'K' as per his studies in Western countries, but the 'K' value estimated for the present condition turns out to be 0.022 indicating a high dispersion and thus a complex model is required to model the heterogeneous traffic conditions.

From the study it was found that, 2W and LMV dominated the platoon composition and LMV's travelled at a higher speed than rest of the vehicles. Large composition of LMV could lead to much larger dispersion in the platoon.

The heterogeneous traffic consists of a mix of vehicle types, where each class travels with a different speed. The current study analyzed all the vehicles for a single value of travel time. However, studying the dispersion for each class of vehicles can lead to much better outputs.

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