# Platoon Dispersion Analysis Based on Diffusion Theory

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**Abstract:** Urbanization and growing demand for travel, causes the traffic system to work ineffectively in most urban areas leading to traffic congestion. Many approaches have been adopted to address this problem, one among them being the signal co-ordination. This can be achieved if the platoon of vehicles that gets discharged at one signal gets green at consecutive signals with minimal delay. However, platoons tend to get dispersed as they travel and this dispersion phenomenon should be taken into account for effective signal coordination. Reported studies in this area are from the homogeneous and lane disciplined traffic conditions. This paper analyse the platoon dispersion characteristics under heterogeneous and lane-less traffic conditions. Out of the various modeling techniques reported, the approach based on diffusion theory is used in this study.The diffusion theory based models so far assumed thedata to follow normal distribution. However, in the present study, the data was found to follow lognormal distribution and hence the implementation was carried out using lognormal distribution. The parameters of lognormal distribution were calibrated for the study condition. For comparison purpose, normal distribution was also calibrated and the results were evaluated. It was found that model with log normal distribution performed better in all cases than the one with normal distribution.

## 1 Introduction

The rapid urbanisation of city areas all over the world is negativelyaffecting the urban mobility. One of the main consequences of urbanization is traffic congestion, where vehicles move at a slower speed leading to increased travel time. Thus,it is imperative to manage the traffic system efficiently using appropriate traffic management methods. A widely used technique to manage the movement of traffic in urban roads is signal control. Traffic signal controls the movement of traffic by sharing the available time separately for conflicting movements topreclude any potential conflicts. Further, it ensures the safety of the vehicles and pedestrians. Hence, awell-designed traffic signal is instrumental in keeping the traffic efficient and safe. In order to design a signal, one must consider different factors that influence the performance of traffic signal. One such factor is the knowledge of platoon dispersion.

Platoons are group of vehicles getting discharged together from a queue at the start of a green signal, which will be travelling together for a distance, before they get dispersed. The rate of dispersion depends on the speed and manoeuvrability of the vehicles present. This phenomenon is called platoon dispersion. Understanding the platoon behaviours will enable us to design and coordinate the successive signals.Coordinating the signals can be achieved if they are close enough for the platoon to reach the downstream signal without much dispersion. In such cases, the green time can be assured for the platoon at the downstream signal, making the total vehicle delay to be minimized.

There have been many studies that looked into the behaviour of platoon vehiclesand thedispersion characteristics of platoon [1-8]. However, most of the studies were reported from homogeneous and lane following traffic conditions. In countries like India, where the heterogeneous traffic consists of multiple classes of vehicles, and no lane-discipline, the platoon dispersion characteristics will be different and the above models may not perform well. Therefore, it warrants a need to study the platoon dispersion under heterogeneous and lane-less traffic conditions and is the aim of the present study. This study analyses the platoon dispersion characteristic under Indian traffic conditions. Data obtained from an urban arterial in Chennai, India, is used for validation.

## 2 Literature Review

There have been several studies starting from 1950's on platoon dispersion [2-10]. In general, the available platoon dispersion models can be classified in to three groups depending on the theories based on which the models were developed, and are: a) Kinematic wave theory based models, b) Recurrence theory based models, and c) Diffusion theory based models.

Kinematic wave theory models was first proposed by Lighthill and Whithman[3], which assumed a functional relationship between flow (q), concentration (k), and distance (x) along the road[11]. Additionally, the shock waves experienced in the traffic is considered to be more “kinematic” than “dynamic”. Geroliminis and Skabardonis [12] combined kinematic wave theory model with Markov theory to develop an analytical model that could be used to estimate platoon dispersion. Ng et al. [13] proposed an integration of Rakha vehicle dynamics model and LWR model to estimate the arrival profile of platoons on signalized intersections. Seddon [11] observed that application of Kinematic theory to platoon dispersion needs information about speed-density relationship, making it less suitable for real time applications.

One of the most popular recurrence theorybased model was proposed by Robertson [1]. In Robertson’s model, the platoon dispersion was explained by flow profiles observed at different points. The downstream flow profiles are estimatedusing the upstream flow profile and the dispersion characteristics. Studies conducted by Lam [14] and Seddon [15] concluded that platoon data predicted by Robertson's model gave predictions closer to the actual values. Similarly, Tarnoff and Parsonson [16] reported good performance of Robertson's model.Fernandez et al.[17] pointed out that even with limitedfield data,Robertson's model has the ability to represent the reality at a reasonable level of accuracy.

The first platoon dispersion model based on diffusion theory was proposed by Pacey [2]. Pacey’smodel assumedthat the vehicles speed isconstant and distributed normally, which is critical to predict downstream flow profile [18].The assumption in Pacey’s model makes it apt for application in steady state traffic condition [19]. Many other studies have used Pacey’s model using the same assumption [6, 18, 20-22]. Pacey’s model has broad applicability in modelling speed distribution, and was shownto be accurate under road conditions without any side interferences [6]. Wang et al.[23] proposed a non-transformation normal distribution based platoon dispersion model. Wei et al.[24]assumed that the platoon speed follows a truncated normal distribution, andthe expected number of vehicles at the downstream wascalculated. Further, differentstudiesvalidated the accuracy of the Pacey’s model by assuming the platoon speeds followed truncated normal distributions [25], log normal distribution [26], truncated Gaussian mixture distribution [27], and truncated mixed phase distribution [28].Dhamaniya and Chandra [29] reported that speeds of vehicles following normal distribution may not be always true under mixed traffic.

Based on the above review, it is clear that not much research has been reportedon platoon dispersion characteristics under heterogeneous and lane-less traffic conditions. The applicability and accuracy of the existing models might not hold if the models were to be used under such condition [30]. The present study is one of the first such studies toanalysethe platoon dispersion process under heterogeneous and lane-less traffic condition based on diffusion theory models.

## 3 Data Collection

An urban road stretch in Chennai, India was chosen for this study. The stretch contains a T-intersection that connects Sardar Patel road and Rajiv Gandhi Salai. The distance of the whole stretch, starting from Madhya Kailash (MK), is nearly 2 km. At the other end of the stretch is the Tidel park intersection. Each direction has 3 lanes with lane width of 3.5m each. A schematic of the study stretch is shown in Figure 1.

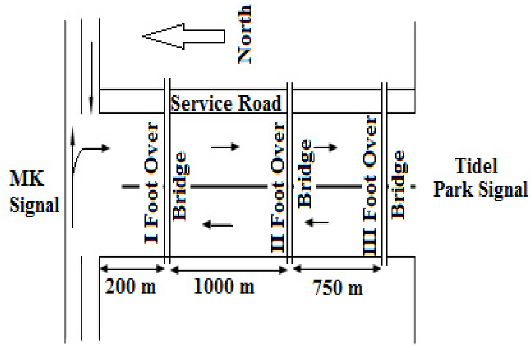


**Figure 1.** Schematic sketch of Study Site showing downstream data collection locations

Traffic flow observed on this stretch was around 100,000 vehicles per day. The vehicles flowing out from the Madhya Kailash intersection in the southbound direction were considered for analysis. Data were collected using video cameras installed at four locations, Madhya Kailash (MK), I Foot over bridge (I FOB), II Foot over bridge (II FOB), and III Foot over bridge (III FOB).Data included the type of vehicle that crosses the reference point, and time of crossing. Vehicles were classified into4 categories: Two-wheelers (2Ws), Three-wheelers (3Ws), Light Motor vehicles (LMVs) that included passenger cars, and light commercial vehicles, and Heavy Motor Vehicles (HMVs), which were mainly buses and trucks. Four days data were collected during three one-hourperiods: 6:30 to 7:30 a.m., 7:30 to 8:30 a.m., and 2:45 to 3:50 p.m. Data were collected during off-peak traffic condition to make the data extraction easy, since the data extraction was carried out manually from the recorded videos. Apart from the flow data at four locations, travel time data for the mentioned time periods were collected using Bluetooth sensor. Bluetooth sensors were placed during the same time as the videos being recorded at the four locations to obtain the travel time for each section. The penetration rate for Bluetooth sensors was found to be around 10%.

## 4 Data Analysis

To start with, the individual vehicle flow data collected were grouped into 5 seconds intervals for all locations and time intervals. The average composition of different classes of vehicles during the study duration was found to be 47%, 41%, 8% and 4% of 2Ws, LMVs, HMVs and

3Ws respectively. It can be seen that 2Ws and LMVs constitute majority of the vehicles.Table 1shows the vehicle flows observed during different time intervals.

**Table 1**. Average flow at different locations during different times of day

| Flow at different locations ( vehicles/ hour) | | | |
|---|---|---|---|
| Location | Duration of day | | |
| | 6.30-7.30 a.m. | 7.30-8.30 a.m. | 2.45-3.50 p.m. |
| MK | 1418 | 1852 | 2627 |
| I FOB | 1695 | 2308 | 3474 |
| II FOB | 1672 | 2245 | 3239 |
| III FOB | 1320 | 1685 | - |

Additionally, a preliminary analysis was conducted on the travel time data collected using Bluetooth (BT) sensors to identify the distribution followed. For this, the IFOB to IIFOB section was selected. Bluetooth data at these two points were gathered and sorted. Bluetooth data mainly consists of two important parameters a) Mac ID, and b) Detected time. Mac ID is a unique alphanumeric sequence assigned to the BT enabled electronic devices. Sensor identifies such electronic devices and records the Mac ID and its time of detection. These data is then screened for outliers and they are compared from consecutive locations to calculate traveltime. An algorithm was written in Matlaband the travel time between IFOB to IIFOB was extracted.

Once the travel time data were extracted, different probability distributions namely, Normal, Weibull, Uniform, Log Normal, Logistic, and Exponential were tried.For each distribution, K-S test [31] was carried out to measure the goodness of fit. The significance level (α) was assumed to be 1%. The K-S test statistic (D) was found and compared with the critical value. Among the different distributions, Log normal was found to fit the travel time data best, followed by Normal distribution. Table 2shows the goodness of fit details. This finding was used in the next stage of analysis.

**Table 2.** Details of the K-S test on fitted distributions

| | Sample size | Significance level (α) | Test Statistic (D) | Critical Value |
|---|---|---|---|---|
| Log Normal | 170 | 1% | 0.07 | 0.12 |
| Normal | 170 | 1% | 0.11 | 0.12 |

## 5 Methodology

In this study, diffusion theory basedplatoon dispersion model [2], is used as the base model and is discussed below.

The rationale behind Pacey's theory is to make use of normal distribution of vehicle speeds to predict arrival of vehicles at downstream locations. It states that if speeds in traffic streams are normally distributed, the dispersion of corresponding platoons can be described by dispersion in speeds under the following assumptions:

i. Vehicles travel at constant speed.
ii. Vehicle speed is independent of platoon position.
iii. There is no overtaking.

Pacey derived travel time distribution of vehicles for a road segment from the assumption that the speed of the vehicles follows normal distribution. Once the travel time distribution is derived the vehicles in the downstream location was predicted. Seddon[18]discretizedPacey'scontinuous equation as the flow pattern will not be represented by a continuous curve. The discretized equation was obtained as

$$q'(t+T) = \sum q(t)\, p(T), \qquad (1)$$

where, $q(t)$isthe flow at upstream location at time $t$, and $q'(t+T)$ is the flow at downstream location at time ($t$+$T$). $p(T)$ is the probability of travel time of $T$. Seddon obtained travel time distribution by assuming that vehicle speed follows normal distribution.However, the actual distribution of travel time need not always be normal and is explored in this study.

As presented in Table 2, the travel time data in the present study followed log normal distribution better than normal distribution. Hence, the above formulation was implemented using log normal distribution instead of normal distribution. Equation 2 shows the probability density function of log normal distribution.

$$p(T) = \frac{1}{(T)\sigma\sqrt{2\pi}} e^{-1/2\left(\frac{\ln(T)-\mu_{\ln}}{\sigma_{\ln}}\right)^2}, \qquad (2)$$

The parameters for the log-normal distribution are $\mu_{\ln}$ and $\sigma_{\ln}$, which are the mean and standard deviation respectively of the natural logarithm of travel time. Calibration of these parameters were done based onthe lowest RMSE between estimated and actual downstream flow. Different values of parameters were tried ($\mu_{\ln}$ranging from 1 to 7 in increments of 0.1 and $\sigma_{\ln}$ranging from 0 to 5 in increments of 0.1). The time interval used was 5 seconds. The set of $\mu_{\ln}$ and $\sigma_{\ln}$values that resulted in lowest RMSE was taken as the best-fit values. The calibrated parameter values obtained are shown in Table 3.

**Table 3**. Calibrated values of parameters values obtained by assuming log-normal distribution of travel times

| | | MK to I | MK to II | MK to III- | I to II | I to III | II to III |
|---|---|---|---|---|---|---|---|
| 6.30 - 7.30 a.m. | $\mu_{ln}$ | 3.60 | 4.40 | 4.80 | 4.30 | 4.20 | 3.60 |
| | $\sigma_{ln}$ | 2.70 | 2.70 | 2.80 | 2.40 | 2.40 | 2.40 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7.30 - 8.30 a.m. | $\mu_{ln}$ | 3.80 | 4.60 | 4.80 | 4.20 | 4.90 | 4.00 |
| | $\sigma_{ln}$ | 2.70 | 2.90 | 2.80 | 2.00 | 3.00 | 2.10 |
| 2.45 - 3.50 p.m. | $\mu_{ln}$ | 4.60 | 5.40 | - | 4.70 | - | - |
| | $\sigma_{ln}$ | 3.00 | 3.10 | - | 2.80 | - | - |

The performance of this model was compared with a model that assumed normal distribution for travel time. The parameters $\mu_n$ and $\sigma_n$, which are the mean and standard deviation of travel times respectively, are the parameters to be calibrated for this model. The same procedure was followed here also. In this case, $\mu_n$ ranging from 0 to 300 seconds (with 5 seconds increment) and $\sigma_n$ranging from 0 to 40 seconds (with increment of 0.1 seconds) were used.For each combination of $\mu_n$ and $\sigma_n$, the RMSE between estimated and actual downstream flow was calculated. The pair of $\mu_n$ and $\sigma_n$that gave the lowest RMSE was taken as the calibrated value. The parameter values obtained are shown in Table 4.

**Table 4**. Calibrated values of parameters values obtained assuming normal distribution of travel times

| | | MK to I | MK to II | MK to III | I to II | I to III | II to III |
|---|---|---|---|---|---|---|---|
| 6.30 - 7.30 a.m. | $\mu_n$ | 30.0 | 75 | 125 | 70 | 85 | 40 |
| | $\sigma_n$ | 14.3 | 14.30 | 17.30 | 11.1 | 9.40 | 10.2 |
| 7.30 - 8.30 a.m. | $\mu_n$ | 35.0 | 110 | 120 | 65 | 125 | 50 |
| | $\sigma_n$ | 12.3 | 15.90 | 18.20 | 8.30 | 17.7 | 6.80 |
| 2.45 - 3.50 p.m. | $\mu_n$ | 85.0 | 185 | - | 95 | - | - |
| | $\sigma_n$ | 17.8 | 20.50 | - | 13.9 | - | - |

The calibrated values from Tables 3 and 4were used to predict the downstream flow. Error is calculated in terms of Root Mean Square Error (RMSE). Table 5 tabulates the RMSE observed for different road segments across different time periods.

**Table 5**. RMSE values obtained for Lognormal (LN) and Normal (N) models

| | | MK to I-FOB | MK to II-FOB | MK to III-FOB | I-FOB to II-FOB | I-FOB to III-FOB | II-FOB to III-FOB |
|---|---|---|---|---|---|---|---|
| 6.30 - 7.30 a.m. | LN | 2.77 | 3.1 | 2.56 | 2.55 | 2.55 | 3.26 |
| | N | 4.21 | 4.41 | 3.21 | 3.31 | 3.43 | 5.22 |
| 7.30 - 8.30 a.m. | LN | 3.12 | 4.24 | 3.98 | 3.92 | 2.67 | 3.89 |
| | N | 5.21 | 6.21 | 4.99 | 5.88 | 4.12 | 5.11 |
| 2.45 - 3.50 p.m. | LN | 5.1 | 4.22 | - | 3.89 | - | - |
| | N | 6.67 | 5.78 | - | 5.22 | - | - |

From Table 5, it can be seen that for all the cases, model that used log normal travel time distribution performed better than the one that used normal distribution.

## 5 Summary and Conclusion

The main objective of this study was to understand the nature of platoon dispersion in a lane less heterogeneous Indian traffic conditions. An urban arterial road stretch in Chennai, India was chosen as the study site. Data were collected by recording videos at four different points of the road. Additionally, travel time data were collected using Bluetooth sensors.Flow datawere extracted at the four locations for three time periods of the day at every 5 sec intervals. Travel time data were analysed to identify the probability distributions it follows using K-S test. Log normal distribution and Normal distribution were found to be bestfits. Methodology used in this study was based onSeddon's model [18]. However, instead of the normal distribution assumed in the original study, the present study used lognormal distribution.The parameters of lognormal distribution were calibrated for the present data. For comparison purpose, normal distribution was also calibrated. It was found that model with log normal distribution performed better in all cases than the one with normal distribution. Though the model employed in this study takes platoon dispersion into account for estimating vehicle arrival, it does not provide any information regarding how external and internal factors impact the dispersion itself. In addition, the methodology can be extended to analyze the arrival profile of different classes of vehicles.

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