# CHARACTERISING PLATOON DISPERSION MODEL ALONG URBAN ARTERIALS UNDER HETEROGENEOUS TRAFFIC

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## ABSTRACT

Traffic signals which forms the integral part of urban road network play a prominent role in maximizing roadway capacity to serve the growing demand for travel, while maintaining a high level of safety. Once released from a signalised stop-line, vehicles normally proceed as platoons and disperse as they progress along the arterial link. Hence modelling of dispersion of vehicle platoon is a key element to measure vehicle arrivals at traffic signals so as to enable efficient coordinated operation of closely spaced traffic signals. At present Robertson's dispersion model is the most extensively used platoon dispersion modeling method. This method relies on the proper calibration of its model parameters - platoon dispersion factor and travel time factor for its application. Studies pertaining to calibration of these two parameters have been conducted extensively under homogeneous traffic conditions, but similar studies have not been conducted adequately considering the diversity of traffic and lack of lane discipline exhibited under heterogeneous traffic conditions. The data for describing platoon dispersion was collected from an urban arterial using videography and was analyzed for each platoon upto 420m at every 30 m interval. The present study developed an empirical model to express travel time factor as a function of parameters describing the nature of heterogeneous traffic (link travel time, vehicle composition and traffic volume). The analyses reveals the trend of variation of platoon dispersion parameters and provide an insight into the platoon dispersion along urban corridors operating under heterogeneous traffic conditions.

## INTRODUCTION

Dispersion or spreading of traffic platoons occurs frequently on urban roads due to the presence of signalised intersections. Group of vehicles travelling together is called as a vehicle platoon. Platoons, which form at the exit of a given traffic signal, do not remain intact or compact as they progress along the arterial link. Platoons may disperse along the road either more quickly or slowly depending on the actual road geometric and traffic conditions existing along the arterial link which may extend to the next traffic signal. The efficiency of a coordination scheme depends largely on the traffic model employed for describing the movement of platoons in signalised links. Thus the coordination problem requires the prediction of vehicle arrivals at traffic signals so as to enable efficient coordinated operation of closely spaced traffic signals.

At present Robertson's dispersion model is extensively by researchers as platoon dispersion modeling method *(1).* This method relies on the proper calibration of its model parameters - platoon dispersion factor and travel time factor for its application. Studies pertaining to calibration of these two parameters have been conducted extensively under homogeneous traffic conditions, but similar studies have not been conducted adequately considering the diversity of traffic and lack of lane discipline exhibited under heterogeneous traffic conditions. Traffic in developing countries like India is heterogeneous in nature consisting of vehicles of different categories with widely varying dimensional and operational characteristics. Therefore, the present study aims to investigate the variation of parameters of Robertson's model at different sections along the downstream of a typical signalized traffic corridor and develop an empirical model to express travel time factor as a function of factors affecting traffic heterogeneity.

## LITERATURE REVIEW

Field observations of platoon dispersion have been noted by researchers as early as in the 1950s. A platoon is a group of vehicles that move with similar speeds and comparatively small spacing. Traffic departing from a traffic signal initially moves as a tight platoon with short vehicle headways. Platoons do not remain in a compact bunch but gradually spread out as they move downstream. Little *(2)* formulated a mixed-integer linear program for an arterial with number of signals in order to maximize the sum of the bandwidths for the two directions. Branch-and-bound algorithms were developed for solving the mixed-integer linear pro-grams by solving sequences of ordinary linear programs. Baras et al. *(3)* modelled urban traffic headway statistics. It was shown that a composite distribution based on the convex combination of a lognormal and a shifted exponential distribution gives a good fit to the observed traffic data. Michapoulos and Pisharody *(4)* studied platoon dynamics at signalized traffic links. Denney *(5)* presented the current state of the art in modelling the dispersion of traffic platoons and introduced a new mechanism which was later tested with detailed field data. Virkler et al. *(6)* developed a statistical procedure to predict the high and low flow rates so as to make traffic models more accurate, based on an assumption of arrival of vehicles in platoons rather than random arrivals. Manar and Baass *(7)* studied dispersion using models contained in the TRANSYT program by defining the platoon dispersion for three types of conditions in relation to external friction. Yu *(8)* developed a technique to calibrate the platoon parameters used in TRANSYT. The technique is based on statistical analysis of link travel time distribution. A mathematical relationship between the average link travel time and its standard deviation ($\sigma^2$) and the platoon dispersion parameters of Robertson's model was established.

Arasan and Kashani *(9)* studied the quality of progression on the downstream of traffic signals particularly on urban roads. They developed heterogeneous traffic flow model which was used to study the quality of arrival type of traffic streams using platoon ratio. The effect of variation in traffic composition for a limited range on traffic platoons was also analyzed. Jiang et.al. *(10)* conducted a study on Indiana highway corridors which investigated vehicle platoon characteristics. Traffic flows was analysed in terms of vehicle platoons, the vital variables - the platoon size, the platoon headway, the platoon speed, and the platoon inter-arrival time. Platooned vehicles were distinguished from non-platooned vehicles using a term critical headway whose value was estimated to be 2.5 s. Skabardonis and Geroliminis *(11)* proposed an analytical methodology for prediction of the platoon arrival profiles and used the kinematic wave theory for studying traffic dispersion. The authors analysed platoon dispersion for distance up to 422m downstream from the signal. Skabardonis and Geroliminis *(12)* proposed an analytical model is to estimate the travel times on arterial streets controlled by traffic signals. Rakha and Farzaneh *(13)* improved the Yu's *(8)* procedure for calibrating TRANSYT-7F platoon dispersion model. The study also developed three generalized platoon dispersion models that explicitly account for the effect of the time step duration on traffic dispersion. The results showed that the predicted flow profile using the proposed platoon dispersion models provides a good fit to field-observed and simulated profiles regardless of the modeling time step considered. The authors also reported that calibrating the value of travel time factor is more significant than the value of the platoon dispersion factor. Puan and Mashros *(14)* explored the pattern of platoon dispersion caused by traffic signal. The authors also found that the tail of the inter-platoon headway skewed to the left and inter-platoon headways did not fit the tested lognormal distribution model.

Mathew et al. *(1)* studied the platoon dispersion under heterogeneous conditions using Robertson's model and suggested that appropriate calibration of its parameters were necessary for using it under Indian conditions. Based on simulation Mauro et al. *(15)* studied platoon distributions on highway facilities with uninterrupted flow. Paul et al. *(16)* calibrated Robertson`s platoon dispersion model in non-lane based mixed traffic operation. Robertson's platoon dispersion model was applied to predict downstream arrivals predicted for observed upstream discharge flow profiles. The model parameters were then calibrated using best fit approach. An empirical model was then developed to express platoon dispersion factor as a function of vehicle composition, normalized flow, link travel time and modeling step size. The literature shows that studies pertaining platoon dispersion modelling have been performed extensively under homogenous conditions but similar studies have not been conducted adequately considering the diversity of traffic and lack of lane discipline exhibited under heterogeneous traffic conditions.

## SCOPE AND OBJECTIVES

In order to facilitate safe and efficient operation of signalized arterials, a better understanding of the platooning phenomenon is needed. The main motives behind the current research include the limited research that has been done in this regard and the significance of determining parameters of Robertson's model under heterogeneous traffic conditions for enabling better planning, management and operation of signalized urban arterials. The research work reported here basically aims at determining one of the major parameters of Robertson's model namely the travel time factor.

The specific objectives of the research work are as follows.

- To determine travel time factor along downstream of signalized arterials
- To identify the trend of variation of parameters of Robertson's model under heterogeneous traffic conditions

## METHODOLOGY

Platoon dispersion models predict the dispersion of a traffic stream as it travels downstream by estimating vehicle arrivals at downstream locations based on an upstream vehicle departure profile and a desired traffic-stream speed. The Robertson model is the most widely used platoon dispersion model *(17)*. Robertson's platoon dispersion model is primarily characterised by two parameters; a platoon dispersion factor (α) and a travel time factor (β). Mathematical form of the model is given in Equation (1).

$$q^d_t = F_n \times q^d_{t-T} + (1-F_n) \times q^d_{t-n} \quad (1)$$

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

$$T = \beta T_a \quad (3)$$

where, $q^d_t$ is arrival flow rate at the downstream signal at time t, $q^d_{t-T}$ is departure flow rate at the upstream signal at time t-T, T is lag time (time gap between initiation of green at upstream stop-line and arrival of first vehicle at downstream stop-line), $T_a$ is average link travel time measured in units of time steps, n is modelling time step duration, and $F_n$ is smoothing factor. The duration over which vehicle discharge counts at stop-line and vehicle arrival counts at reference sections are aggregated is defined as modelling step size. Since, Robertson's model estimates the downstream flow at a given time interval, the model needs to be applied recursively to predict the flow. Hence Seddon *(18)* modified the mathematical form as given by Equation (4).

$$\sum_{i=T}^{\infty} F_n(1-F_n)^{i-T} \times q_{t-i+T} \quad (4)$$

The above equation demonstrates that predicted downstream arrivals follow a shifted geometric series, which estimates the contribution of an upstream flow in $(t-i)^{th}$ interval to the downstream flow in $t^{-th}$ interval. At present Robertson's dispersion model is the most extensively used platoon dispersion modeling method. This method relies on the proper calibration of its model parameters - platoon dispersion factor and travel time factor for its application. Studies pertaining to calibration of these two parameters have been conducted extensively under homogeneous traffic conditions, but similar studies have not been conducted adequately considering the diversity of traffic and lack of lane discipline exhibited under heterogeneous traffic conditions.

In the current study, the method developed by Rakha and Farzaneh *(13)* is used for determining the Robertson platoon dispersion factors (α and β) directly using the basic properties of a geometric distribution. The following three equations show their formulation.

$$\beta_n = \frac{2T_a' + n - \sqrt{n^2 + 4\sigma'^2}}{2T_a'} \quad (5)$$

$$\alpha_n = \frac{1-\beta_n}{\beta_n} \quad (6)$$

$$F_n = n\frac{\sqrt{n^2 + 4\sigma'^2} - n}{2\sigma'^2} = \frac{1}{1+\alpha_n\beta_n T_a} = \frac{n}{n + (1-\beta_n)T_a'} \quad (7)$$

where $\beta_n$, $F_n$, and $\alpha_n$ are model parameters for step size of n sec; σ' standard deviation of link travel times (s) and $T_a$' is the mean roadway travel time (s). The travel time factor values thus determined were used as the basis for modelling travel time factor as function of various parameters such as vehicle composition, link travel time and traffic volume which describe the nature of heterogeneous traffic.

## DATA COLLECTION

The important roadway features considered in selecting the study locations include straight and level four lane divided road stretch with uniform cross section free from side frictions located on the downstream of signalised intersection. An at grade intersection in Thiruvananthapuram city located in the southernmost state of Kerala, India was selected which satisfied the conditions. The width of the road space available for each direction of flow on the road is 7.5 m. Geometric details of the study stretches like width of approach, dimensions of channelising islands, length of the stretch were collected manually. The traffic data was collected using video graphic survey technique at the selected study locations, covering entire road sections from stop line up to 420 m downstream of the signals. To facilitate detailed analysis on vehicular movement from stop line to downstream the entire study stretch was divided into 30 m sections. Traffic data at the selected study stretch was collected by mounting video cameras at multiple vantage points simultaneously thereby conducting video surveys for two hours on a week day during morning peak hour and off peak hour. Figure 1 shows the snapshots of the study stretch from the camera locations.

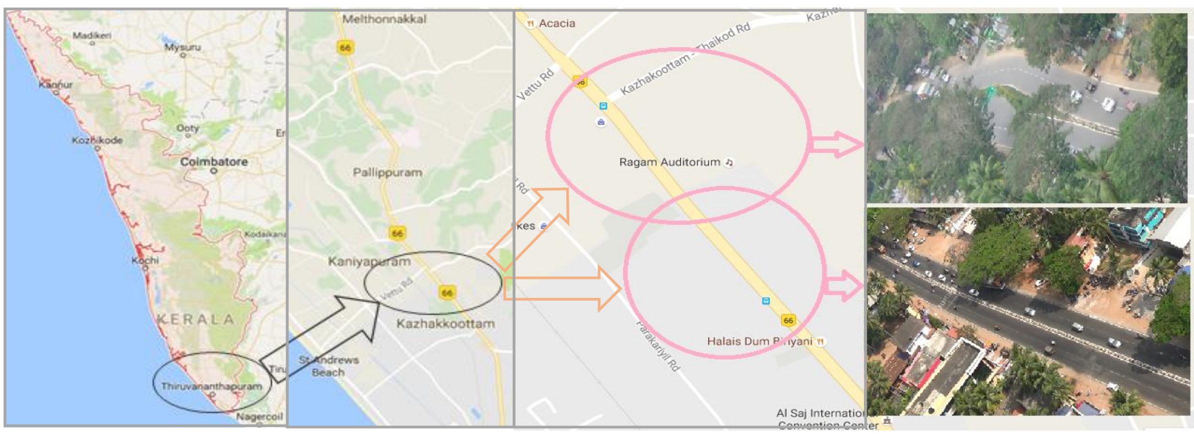


**FIGURE 1 Google maps image of the site along with snapshots**

The vehicles observed in the selected intersection were classified into five (Buses, Light Commercial Vehicles (L.C.V.), Cars, Motorised Three Wheelers (M.Th.W.) and Motorised Two Wheelers (M.T.W.)) different categories of vehicles. The category-wise vehicular arrival times of vehicles at each of the reference lines at every 30 m were made for each of the green times of the cycle length. The observed traffic flow during study period was moderate to heavy with discharge in the range of 25 vehicles per cycle to 42 vehicles per cycle. The average vehicle composition of traffic streams, as observed during the study period consists of 36.38% cars, 36.85 % M.T.W., 13.62% M.Th.W., 6.68% L.C.V. and 6.48% buses. The average overall dimensions for the different types of vehicles as taken from an earlier study are given in Table 1 *(19).*

**TABLE 1 Average Overall Dimensions of Different Types of Vehicles**

| Vehicle type | Average Overall dimension (m) | |
|---|---|---|
| | Length | Breadth |
| Buses | 10.3 | 2.5 |
| Light Commercial Vehicles (L.C.V.) | 5.0 | 1.9 |
| Cars | 4.0 | 1.6 |
| Motorised Three-Wheelers (M.Th.W.) | 2.6 | 1.4 |
| Motorised Two-Wheelers (M.T.W.) | 1.8 | 0.6 |

## DEVELOPMENT OF MODEL FOR ESTIMATING TRAVEL TIME FACTOR

Travel time factor (β) exhibits variation in the context of link travel time, standard deviation of link travel times and modelling step size. The heterogeneous nature of vehicles with widely varying dimensional and operational characteristics also accounts for this variation. Hence the development of a model to predict the value of β which takes into account the various factors explaining the heterogeneity is necessary. In order to consider the effect of traffic composition, the observed vehicular categories were grouped into two namely large vehicles (LV) and small vehicles (SV) on the basis of area occupied by the vehicles. The large vehicles include light commercial vehicles and buses whereas small vehicles include motorized two wheelers and motorized three wheelers. To account the effect of traffic volume, volume to capacity ratio (V/C) values were used. For determining capacity, heterogeneous traffic flows were simulated using VISSIM software for an at grade signalized intersection on 7.5 m wide road space for the field observed traffic compositions. The peculiar characteristics of lack of lane discipline and frequent lateral movements under heterogeneous traffic were incorporated into the model by changing the default parameters in the VISSIM.  The values of various parameters were modified based on field observations and studies conducted by other researchers *((20), (21), (22))* on heterogeneous traffic flow. The capacity for the traffic on arterial under consideration during green times is obtained by varying the input volume and observing when the output volume is maximum. To capture the variations in link travel time exhibited by various vehicle categories, the link travel time of cars and its standard deviation were used. The model developed for estimating travel time factor is given below as equation (8).

$$\beta_n = \frac{0.93 \times e^{(\frac{V}{C} \times (LV+SV))}}{n^{0.003}(1+\log(\frac{30\sigma_c}{T_C}))} \tag{8}$$

where $\beta_n$ is the travel time factor for step size of n sec; $\sigma_c$ is standard deviation of link travel times of cars in sec and $T_c$ is the mean roadway travel time of cars in sec, V/C is the volume to capacity ratio, SV is the composition of small vehicles and LV is the composition of large vehicles.

Modelling step size is a significant parameter which is critical for calibration of Robertson’s dispersion model. In present study, four modelling step sizes viz. 1 sec, 2 sec, 4 sec and 8 sec are investigated. Root Mean Square Error (RMSE) is the standard deviation of the prediction errors. The formula is:

$$\text{RMSE} = = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(p-o)^2\right)} \tag{9}$$

where p is the predicted value and o is the observed value. Root mean square error (RMSE) (in vehicle/s) is estimated for each selected modelling step size using the predicted and observed values of travel time factor and is shown in Table 2. The graph depicting the observed and predicted values of β using the developed model is shown in Figure 2. The variation in model parameters of Robertson’s model at various volume capacity ratios at modelling step of 4sec is shown in figures 3 and 4. The obtained mean absolute percentage errors (MAPE) of predicted β values were less than 20% indicating that the forecasted values are good as per Lewis scale *(23)*.

**TABLE 2 RMSE Values at Various Modelling Time Steps**

| Distance (m) | RMSE (veh/s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | n = 1s | | n = 2sec | | n = 4sec | | n = 8sec | |
| | Observed β | Predicted β | Observed β | Predicted β | Observed β | Predicted β | Observed β | Predicted β |
| 120 | 0.5425 | 0.5375 | 0.385 | 0.415 | 0.2325 | 0.3075 | 0.1625 | 0.4275 |
| 240 | 0.545 | 0.5475 | 0.3625 | 0.380 | 0.29 | 0.3075 | 0.235 | 0.4225 |
| 360 | 0.6125 | 0.6125 | 0.4325 | 0.425 | 0.3475 | 0.355 | 0.2925 | 0.415 |

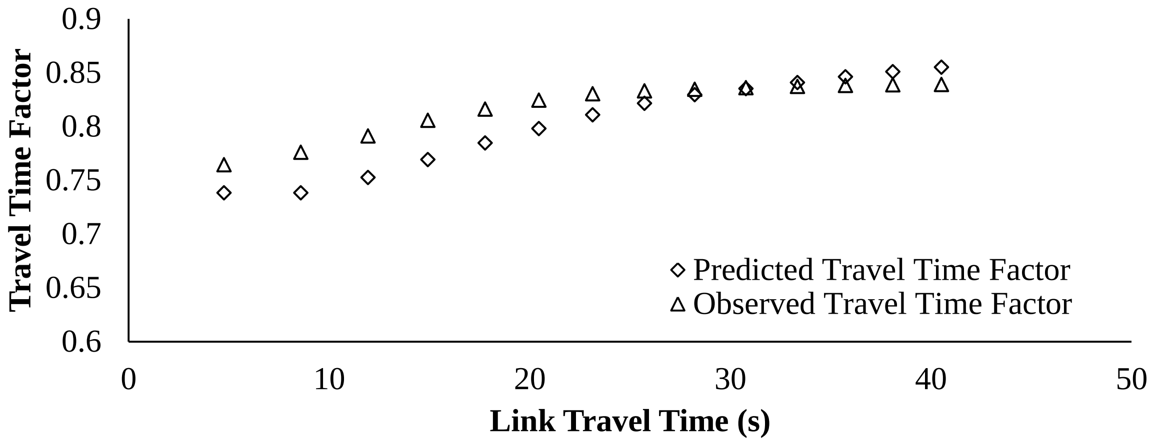


**FIGURE 2 Variation of predicted and observed travel time factor**

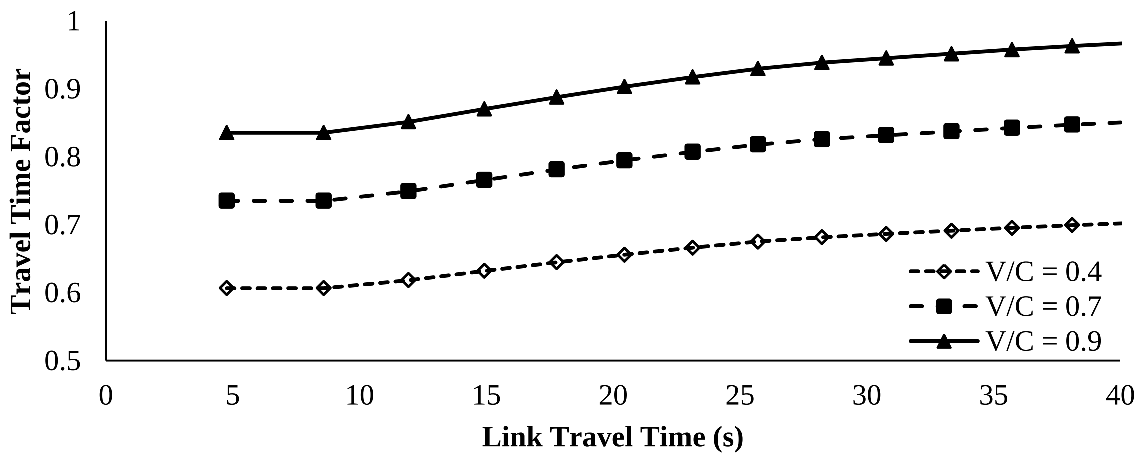


**FIGURE 3 Variation of travel time factor at different volume levels**

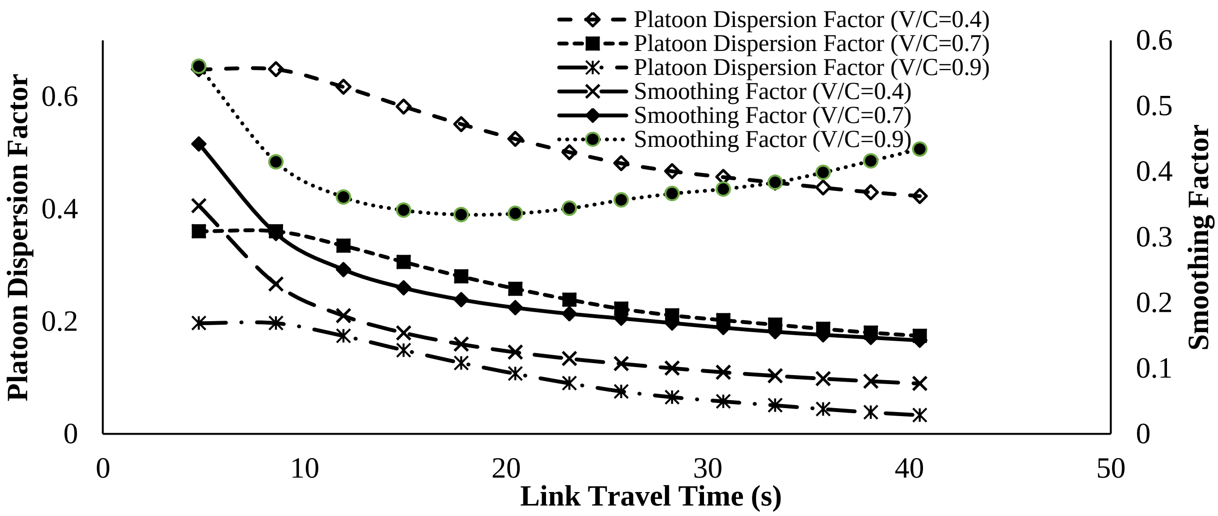


**FIGURE 4 Variation of platoon dispersion factor and smoothing factor with volume**

## CONCLUSIONS

Robertson's dispersion model which is the most extensively used platoon dispersion model relies on the proper calibration of its model parameters - platoon dispersion factor and travel time factor for its application. The present study investigated the variation of parameters of Robertson's model at different sections along the downstream of a typical signalized traffic corridor in urban India. This study also developed an empirical model to determine the travel time factor of Robertson's model by incorporating various factors which explain the heterogeneity under Indian traffic conditions. The predicted values of travel time factor (β) ranges from 0.71 to 0.96 for different observed traffic conditions. The analyses of Robertson model parameters revealed the trend of variation of platoon dispersion parameters and provided an insight into the platoon dispersion along urban corridors operating under non-lane based heterogeneous traffic conditions.

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