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Platoon Diffusion along Signalized Corridors

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Abstract

Management and control of traffic flow on urban arterial streets with traffic signals at intersections actualize platoons at the exit of a given traffic signal, which do not remain intact as they progress along the arterial link and tend to disperse. The platoon characterizing variables such as platoon size, intra-platoon headway, inter-platoon headway and platoon speed has been studied extensively under homogeneous traffic conditions but such similar studies have not been conducted adequately considering the diversity of traffic and lack of lane discipline exhibited under heterogeneous traffic conditions. This study enables better understanding of platoon characterizing variables under heterogeneous traffic conditions facilitating enhanced safety and better operation. Data were collected using video graphic survey technique. It was analyzed for each platoon upto 420m at every 30 m interval. The analyses revealed the trend and dispersion of platoons of vehicles and locations where initial platoon diffusion and higher platoon diffusion occur at downstream of traffic signals.

Keywords: Traffic signal; platoon; heterogeneous; platoon diffusion

1. Introduction

Traffic problems pertaining to intersections include traffic delay, congestion, safety and pollution. The prime intention of implementing traffic control measures at highway intersections is to provide safe movement for conflicting vehicle flows with minimum possible traffic delay. Platoons formed at the traffic signals may disperse

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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. Hence the study of platoon dispersion is important in the design of traffic engineering facilities, such as intersection design, and traffic signal linking systems. The platoon characterizing variables such as platoon size, intra-platoon headway, inter-platoon headway and platoon speed have been studied extensively under homogeneous traffic conditions, but only limited studies have been reported under heterogeneous traffic conditions. In this work an attempt is made to study the trend and diffusion of platoons of vehicles and locations where initial and higher platoon diffusion occurred at downstream of traffic signals based on the variations exhibited by the platoon characterizing variables.

2. 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. Little [1] 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 programs by solving sequences of ordinary linear programs. Baras et al. [2] 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 [3] studied platoon dynamics at signalized traffic links. Denney [4] 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. [5] 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 [6] studied dispersion using models contained in the TRANSYT program by defining the platoon dispersion for three types of conditions in relation to external friction. Arasanan and Kashani [7] 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. [8] 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 [9] 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 [10] proposed an analytical model is to estimate the travel times on arterial streets controlled by traffic signals. Puan and Mashros [11] 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. [12] 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. [13] studied platoon distributions on highway facilities with uninterrupted flow.

Although several literature are available for predicting platoon dispersion under homogeneous traffic conditions, relatively little is known about platoon dispersion modelling and behaviour under heterogeneous traffic conditions. The road traffic on the urban roads in developing countries like India is highly heterogeneous with vehicles of wide ranging static and dynamic characteristics. There are about eight (Buses, Trucks Light commercial vehicles, Cars, Motorised three-wheelers, Motorised two-wheelers, Bicycles and Tricycles) different categories of vehicles with wide ranging static and dynamic characteristics plying on Indian roads. Such road traffic in which the cars constitute only about 30% or less, is termed as heterogeneous traffic. Another striking feature of the road traffic operating condition in developing countries is that, despite having lane markings, most of the time lane discipline is not followed. At intersections, there is a significant lateral movement, primarily by the smaller sized motor vehicles (bicycles, motorcycles, mopeds, and scooters) and vehicles tend to use lateral gaps to reach the head of the queue.
The study proposed here is concerned with quantification of trend of platoon progression at signalized urban corridors due to the variation in traffic mix.

3. Objectives of the Research Work

The research work reported here basically aims at studying the platooning characteristics and vehicular interactions of various categories of vehicles under heterogeneous traffic conditions which will provide a foundation to analyze traffic flows in terms of vehicle platoons rather than individual vehicles.

The objectives of the research work are as follows.

- To plot the speed – distance graphs for various categories of vehicles which stopped during red and proceeded through the intersection after getting green as well as for vehicles which arrived during the green times.
- To identify the locations where initial and higher platoon diffusion occurs at downstream of traffic signals on the basis of the variation in relative standard deviation of platoon characterizing variables.

4. Field Data Collection

The important roadway features considered in selecting the study location include straight and level stretch with uniform cross section of road free from side frictions on the downstream of signalisation intersection. At grade intersections located in an urban area controlled by traffic signals where one of the intersecting roads is a four lane divided was required for this study. An at grade three legged intersection at Vettu Road 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.

Vehicles released from a signal often maintain their grouping for well over 335 m [14]. Skabardonis and Geroliminis [10] suggested that the platoon dispersion analysis has to be conducted for distance longer than 150 m (500ft) for platoons with platoon ratio is smaller than 0.9. While, according to Transportation Research Institute [15], platoon dispersion models showed that greater dispersion occurs over a distance of 402 m (0.25 mile). The platoon dispersion model used in the Highway Capacity Manual [16] assumes that the effects of platooning from an upstream signal will disperse at about 402.3 m (0.25mile) downstream from the signal. As seen from the reported studies it is clear that, there is no commonly accepted criteria for the selection of distance to be adopted for platoon dispersion analysis at downstream of the traffic signal. It was decided to collect traffic data using video graphic survey technique at the selected study location, covering entire road sections up to 420 m downstream of the signals. To facilitate detailed analysis regarding platoon dispersion characteristics the entire study stretch (420 m after stop line and 60 m before stop line) was divided into 30 m sections. Traffic data at the selected study stretches were collected by mounting video cameras at multiple vantage points simultaneously thereby conducting video surveys for one hour on a week day during morning peak hour. The traffic signal cycle timings were also recorded manually using a stop watch.

5. Data Extraction

The traffic flow was recorded using a video cameras mounted at vantage points, which enabled recording of all the traffic flow characteristics at the same time. The video film obtained was transferred to a computer work station to extract the required data pertaining to platoon characteristics like volume, composition and inter arrival time. The vehicles observed in the selected intersection were classified into five (Buses, Light Commercial Vehicles, Cars, Motorised Three Wheelers and Motorised Two Wheelers) different categories of vehicles. The observations were noted for 20 cycle lengths during green times. The category-wise vehicular observations were recorded during the observed cycle lengths. Under heterogeneous traffic like the one found in developed countries, vehicles occupy any possible lateral position on the entire width of the road and move without any lane discipline. Under this circumstances, it will be inappropriate to consider and analyse the traffic flow based on lane, as done in homogeneous traffic conditions. The arrival times of vehicles at each of the reference lines were noted along with the category of vehicles.
6. Data Analysis

 Platoons of vehicles accumulated at traffic signal during the red cycle tend to dissipate when the signal turns green in a haphazard manner owing to the traffic heterogeneity witnessed on Indian cities. Due to the peculiar characteristics of heterogeneous traffic as mentioned earlier during maneuver, the vehicles tend to take any lateral position along the width of roadway, based on the space availability. Under the above traffic conditions, quantification of change in vehicular interactions, over a wide range of roadway and traffic conditions, can be done better by taking speed as the measure of performance, since it reflects the various factors contributing to the overall influence of the type of vehicle on the performance of the traffic stream under platooned vehicular movement. Speed is a performance measure which is accurately measurable and easily perceived by all users of a roadway and also provides a clear picture of how smoothly a facility is operating. From the observed vehicular arrival times at every 30m reference points from stop line considering the entire width of the road, the travel time between each of these reference points for each vehicle category was found out. As speed is inversely related to travel time between the fixed reference points, the recorded travel times were used to plot the speed-distance graphs for various categories of vehicles. Separate plots were prepared for vehicles which stopped during red and proceeded through the intersection after getting green as well as vehicles which arrived during the green times. Speed distance profile of both categories of vehicles were plotted. An example of speed distance plot developed for cars is shown in Fig. 1. Speed versus distance plots for various other categories of vehicles were also plotted. This is depicted in Fig. 2.

As the platoon moves downstream away from the traffic signals where it was released, first differences in rate of acceleration, later, differences in speeds of individual vehicles and vehicular interactions, cause the platoon to extend its length thereby inducing the phenomenon called platoon dispersion. The dispersion linearly relates to distance from the signal and the line's slope presented on a time/distance chart could be taken as a measure of dispersion. Also the patterns of mean speeds could be used to describe the platoon movement. The spreading out or dispersion of platoons is primarily due to the result of different drivers having different desired speeds. Faster drivers pull away quickly whereas the slower drivers gets lagged behind. Platoon dispersion is considered to be less
when the standard deviation of individual driver’s desired speeds is small and when the speed of progression equals the driver’s desired average speed. Hence a platoon which gets released from the signal will be experiencing higher tendency to disperse until the drivers attain desired average speeds and can assumed to have experienced some sort of dispersion when the speed difference along the considered reference points is minimum. This can be seen from the average speed – distance graph depicted in Fig. 2 where the difference in speeds and vehicular interaction causes the platoon to undergo spreading along the road stretch up to 180 m beyond which the speed difference is minimal for 180 m till 210 m, after which the drivers again gain momentum trying to attain higher average desired speeds causing the platoons to disperse further till 360 m beyond which speed difference is minimal till 420 m suggesting that the drivers have attained average desired cruising speeds under urban conditions. The same trend was also seen in respect of the graphs plotted for various categories of vehicles. Thus from the graphs depicted in Fig.1 and 2, it can be seen that initial dispersion occurs at 180 m – 210 m and higher dispersion occurs at 360 m - 420 m under urban conditions for a four lane divided road.

To check for the validity of the said reason for the trend in platoon dispersion, the variation in the speed difference between the 30m reference points were estimated. For this purpose, the difference in speed change, was calculated as the difference between average stream speeds along the two adjacent reference points. Then, plots depicting the speed difference over distance were made as shown in Fig.3. From the plot, it can be noted that the histogram, showing the speed difference over distance, exhibit the same pattern as that of the variation average stream speed of vehicles in the platoon. Thus, it can be understood that the initial and higher platoon dispersion is directly related to the change in speed difference between the average stream speeds along the two adjacent reference points.

In order to further augment the identification of road section on the downstream of isolated intersection where initial and higher dispersion occurs, it was decided to plot the relative standard deviation (RSD) over distance for speeds of queued vehicles, vehicles arriving during the green times, entire stream of vehicles and for inter vehicular arrival times of vehicles arriving at the reference points. The relative standard deviation is defined as the ratio of the standard deviation to the mean expressed as percentage. The RSD will depict higher variation whenever the platoons encounter disturbances which acts as an indicator of traffic conditions thereby indicating platoon spreading. The plotted graph is depicted in Fig.4. From the Fig.4. it could be seen that the variation of RSD for the trend lines is minimum at road sections of 180 m -210 m and 360 m - 420 m which underlines the observation made earlier that initial and higher dispersion occurs over these regions.
7. Platoon Characterisation

The basic traffic flow characteristics to describe the performance of any road network include traffic flow rate and speed. Hence in this research work it was decided to select platoon size, intra-platoon arrival time and inter-arrival time between consecutive platoons to analyze the characteristics of platoon based traffic flows. The selected platoon variables, along with the appropriate critical inter vehicular arrival time provide a basis for characterizing platoon based traffic data collection and analysis.

7.1. Determination of Critical Inter Vehicular Arrival Time

The selection of a proper value of the critical inter vehicular arrival time is important because a small change in the critical inter vehicular arrival time will bring about huge changes in the resultant platoon characteristics. Platoon sizes range from two to any number of consecutive vehicles with headways less than the chosen critical inter vehicular arrival time. In this study, platoon size was classified based on inter vehicular arrival times of 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6 and 4.0s for each of the reference points located at every 30 m intervals from 0m at intersection to 420 m downstream of intersection. The dispersion of platoons was measured by examining the relationship between the platoon size and the coefficient of variation of the platoon size so as to enable the determination of a proper value of critical inter vehicular arrival time. The coefficient of variation (COV) of platoon size is defined as the ratio of the standard deviation of platoon size to the average platoon size [8]. The proportions of platooned vehicles and COV values corresponding to different inter vehicular arrival time were plotted to determine critical inter vehicular arrival time at the reference points. Critical inter vehicular arrival times at reference points were identified and was used for subsequent platoon characterization analysis. The variation of critical inter vehicular arrival times has been depicted in Fig.5.

![Fig. 5. Variation of critical inter arrival time](image)

7.2. Inter Platoon Vehicular Arrival Time

Inter platoon vehicular arrival time is defined as the time interval between two successive platoons. That is, platoon inter arrival time is the time gap between the last vehicle of a platoon and the first vehicle of the successive platoon. It was observed from the study that the platoon inter-arrival times range from 1.6 s to 9 s. The minimum observed platoon inter arrival time is restricted by the critical arrival time at every reference points. The variation of relative standard deviation (RSD) over distance for inter platoon vehicular arrival time of vehicles arriving at the reference points was plotted and is depicted in Fig.6.

![Fig. 6. Variation of RSD of inter platoon vehicular arrival time](image)
7.3. **Intra Platoon Vehicular Arrival Time**

Intra platoon vehicular arrival time is defined as the average of individual headways within a vehicle platoon. This definition is an explanation of the actual arrival times within a platoon because the individual inter vehicular arrival times within a platoon are diverse in reality. But individual vehicular arrival time and intra platoon vehicular arrival times differ in statistical characteristics due to the fact that the maximum intra platoon vehicular arrival time is limited to critical arrival time, but the individual inter vehicular arrival time has no upper limit [8]. The variation of RSD over distance for intra platoon vehicular arrival time of vehicles arriving at the reference points was plotted and is depicted in Fig.7.

![Variation of RSD of intra platoon vehicular arrival time](image)

**Fig. 7. Variation of RSD of intra platoon vehicular arrival time**

7.4. **Trend of Platoon Dispersion**

Platoon dispersion is the common phenomenon on urban arterial road in which traffic departing a traffic signal initially moves as a compact platoon with short vehicle headways gets gradually spread out as they move downstream owing to differences in vehicle speeds and vehicle interactions. The spreading out or dispersion of platoons is primarily due to the result of different drivers having different desired speeds. Hence a platoon which gets released from the signal will be experiencing higher tendency to disperse until the drivers attain desired average speeds and can be assumed to have experienced some sort of dispersion when the critical inter vehicular arrival times computed remains more or less uniform along the distance downstream of intersection as observed from Fig.5. This is due to the fact that once the drivers attain desired speeds vehicular interaction will be less causing minimum variation in speed leading to limited variation in critical inter vehicular arrival times over distance as seen over 180 m to 210 m depicted in Fig.5 suggesting the occurrence of initial dispersion over that stretch. Beyond the 180 m - 210 m stretch an increasing trend is exhibited by critical inter vehicular arrival times up to 360 m. The root cause for the said trend is the drivers urge to attain higher desired speeds resulting in greater variation in speeds between vehicles causing more diffusion of platoons as exhibited by the variation of critical inter vehicular arrival times. Beyond 360 m up to 420 m the variation of critical inter vehicular arrival times tends to be minimal advocating the occurrence of less dispersion commending the occurrence of higher dispersion over that stretch.

In order to augment the identification of road section on the downstream of isolated intersection where initial and higher dispersion occurs, it was decided to plot the variation of RSD over distance for inter platoon and intra platoon vehicular arrival times of vehicles arriving at the reference points. The RSD will depict higher variation whenever the platoons encounter disturbances which acts as an indicator of traffic conditions thereby indicating more platoon spreading. The plotted graphs are depicted in Fig. 6 and 7. From the figures it could be seen that the variation of RSD depicted by trend lines is minimum at road sections of 180 m - 210 m and 360 m- 420 m which corroborates the claim of occurrence of initial and higher dispersion over these regions.

8. **Conclusions**

The following are the major conclusions of the study:
1. When speed is used as a measure of performance to study diffusion, it is found that under heterogeneous traffic conditions, the trend of dispersion depicted by various categories of vehicles is similar.
2. Speed – distance plots of cars depict that the initial dispersion occurs at 150 m and higher dispersion occurs at 360 m under heterogeneous traffic conditions which explains that dispersion phenomenon occurs slightly
ahead of the distances suggested for homogenous traffic. The causative reason for this phenomenon can be attributed to the lack of lane discipline exhibited by cars under heterogeneous traffic.

3. For vehicles which are smaller than cars (M.Th.W and M.T.W.) the initial dispersion was found to occur at 120 m and higher dispersion at 360 m. Thus it can be inferred these categories of vehicles reach desirable speeds much earlier than car. The reason for which may be attributed to the easy maneuverability which helps them to attain desirable speeds prior to that of cars.

4. It was also found from the speed-distance plots developed for vehicles which are larger than cars (L.C.V. and Buses) that initial dispersion occurs at 180 m and higher dispersion occurs at 360 m, the reason for which may be due to the poor maneuverability and larger static characteristics of these category of vehicles which helps to attain desirable speeds only at a later distance when compared to that of cars.

5. It was also observed that higher diffusion for all category of vehicles were found to occur at 360m irrespective of the nature of static and dynamic characteristics.

6. The variation of relative standard deviation over distance of vehicles also substantiated the above findings that the initial diffusion occurred at road sections of 180 m - 210 m and higher diffusion occurred at 360 m - 420 m.

7. It is observed that the trend lines showing the variation of relative standard deviation over distance of platoon characterising variables like intra platoon arrival time and inter platoon arrival time exhibited minimum variation at road sections of 180 m - 210 m and 360 m - 420 m indicating the occurrence of initial and higher dispersion over these regions.

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