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**Research Article**

# Vehicles Platooning Behaviour and Level of Service on Indian Expressway

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**ABSTRACT**

Expressways in India are significantly different from other roads; however, surprisingly, some common phenomena, such as platooning, also occur on expressways just as they do on urban roads. This paper investigates the formation of vehicle platoons and their identification based on headway measurements. This study identifies the use of a critical or platooning headway to differentiate between platooned and free vehicles on roadways. Specifically, it investigates the determination of platooning headway for the Mumbai-Pune expressway in India, where frequent platoons are observed. Using the average coefficient of variation within a platoon method, a platooning headway of 1.3 seconds was found. The study focuses on the basic section of the expressway and uses video graphic data collected from high-resolution cameras during both peak and off-peak hours for over six hours. The study examines platoon formations and parameters, such as platoon rate and average vehicles per platoon, with respect to different traffic volume levels. The relationship between average platoon size and traffic volume is found to be exponential, while the relationship between platoon rate and directional volume is an inverse parabolic curve. Platoon frequency, heavy vehicle percentage, and other parameters are also studied, revealing that the presence of heavy vehicles and number of vehicles significantly affect the average speed of the platoon. Finally, new levels of service (LOS) criteria for expressway based on platoon parameters are proposed.

**Keywords:** *platooning, platoon rate, expressways, platoon headway, Level of service*

## 1. INTRODUCTION

Expressways in India represent the highest tier of roads, being controlled-access highways specifically designed for high-speed travel and featuring grade-separated intersections. These roads prohibit slow-moving vehicles like auto-rickshaws and non-motorized vehicles. Although they make up just about 4,138 km of India's extensive 6,373,000 km road network (Basic Road Statistics of India 2017-18), major expressways include the Mumbai-Pune Expressway, Ahmedabad-Vadodara Expressway, and Delhi-Meerut Expressway. However, maintaining optimal vehicle speeds on these expressways can be challenging due to factors such as the diversity in vehicle sizes, speeds, and usage, along with inconsistent lane discipline that varies with traffic and site conditions. This inconsistent behaviour on expressways is a primary cause of platoon formation.

The primary object is to analyse and study the headways which are primarily time headways, the elapsed time between two successive vehicles. The intent is to find a method for a suitable critical headway for identification of platooning of vehicles on Mumbai-Pune expressways. Time headway is dependent on many factors such as vehicle length and size, traffic volume, lane position, day of time, weather conditions. Time headway is an important parameter which has significant effect on capacity, level of service as well as on safety of expressways and highways.

Platoon or bunching is a common behaviour observed among drivers while driving on highways. On expressways, platooning behaviour is observed when vehicles moving closely to each other and being controlled as one unit. Generally, it happens when fast-moving vehicles catching up with the slower moving vehicles and not being able to pass. Buses, trucks and light commercial vehicles generally have lower speeds and poorer acceleration capabilities as compared standard passenger cars therefore more likely to be caught by fast moving passenger cars. In addition to that, once caught in a platoon, it's difficult for passenger cars to pass. This peculiar behaviour has been o0bserved on expressways because of Heavy vehicles (HV) and slower moving vehicles. Bigger vehicle like HV, because of their height, width or length obstructs the follower vehicles sight and causes platoon to form up. Although platoons are defined by their leaders, leaders too experience little frustration or reduction in safety as a result of being in a platoon. They are generally not delayed and, except for some pressure from the following vehicles. It is principally the followers who suffer the largest reduction in service; they may be delayed, frustrated and even caused to attempt unsafe passing manoeuvres. Platooning behaviour on Mumbai-Pune expressway is studied thoroughly in this paper.

## 2. LITERATURE REVIEW

Time headway is dependent on many factors such as vehicle length, size, volume level, lane position, weather condition on highways or expressways. This section reviews the existing and old methods of determination of critical headway for identification of platooned vehicles and different statistical investigation works done by different researchers.

Many factors influence the headway distribution of vehicles on expressways. A study on different distribution for time headways on a four-lane highway and found that lognormal distributions are best fit for the headways obtained during high traffic volumes [17]. A summary on headways [1] defined the critical headway criteria for platoon and suggested some distinct states of platoon. Lay gave the headway conditions as: (a) headway having less than 2.5 second implicates that the traffic is in following condition, (b) headway in between 2.5 to 9 second suggests that traffic is in either in following or free condition, (c) headway more than 9 second shows that the traffic is in free condition. Whereas, [2] studies on car following conditions mentioned a headway of 3.5 sec and 5 sec as critical headways for passenger car and Heavy vehicle respectively for defining car following condition on freeways under congested conditions. studied on platoon formation and its characteristics lane to lane and cross section basis by using data of different 18 locations of Tomei expressway which is a multilane expressway. Critical headway of 3 second and 4 second were taken for platoon criteria for cars and heavy vehicles on Tomei expressways for a study on platoon [12].

A study on heavy duty vehicle platooning [16] mentioned that platooning of heavy-duty vehicles can improve fuel efficiency and safety aspects on roads. Different platoon parameters such as average platoon size and platoon rate were studied by them. A study on the mechanism behind traffic breakdown was studied [3] and proposed a model which included and simulated both stochastic and dynamic processes of traffic flow at bottlenecks. This model works on basis of two ideas, first is platoon formation behind a bottleneck and speed transitions within a platoon. Aerde and Yagar [4] did a detailed study on capacity, speed and platooning on two-lane rural highways using 37 different two-lane rural highways in Ontario. Effect of trucks were significant on highways for causing platooning. Keller [7] studied on the effects of a 100km/hr speed limit on before and after of platoons of vehicles. Platoon rate, number of vehicles and platoon size were analysed as a function of flow rate. He concluded that speed of vehicles and size of platoons didn't get affect significantly due to speed limit. Lane to lane variations in speed and volume are site and volume dependent as suggested by the research conducted [11]. They analysed 30 days of detector data from Queen Elizabeth way freeway near Toronto. Their analysis showed that speed and flow relationship vary across different lanes. Taweesilp et al. [12] did a study on measuring LOS on expressways by using platoon characteristics on Tomei expressway. They studied on platoon characteristics such as percent followers, platoon rate and platoon size and proposed LOS which is based on these parameters. Laufer [13] did research on freeway capacity, saturation flow and the car following behavioural algorithm of VISSIM microsimulation software. Yousif et al. [8] studied the behaviour of lane utilization on United Kingdom Motorways. The literature on the traffic flow on expressways in India is scarce. The limited research on expressways in India include the studies by Ponnu et al. [10] on lane usage, following behaviour and time gap models analysis for a multi-lane freeway in India.

## 3. STUDY LOCATION AND DATA ANALYSIS

This section outlines the methodology used for data collection and analysis. It covers the rationale for selecting the location, the framework for gathering data, and the extraction of key parameters from the raw data. Video recordings were made at various points along the Mumbai-Pune expressway for this purpose.
The parameters were extracted frame to frame for a better accuracy of results and analysed.

**Figure 1 Locations for data collection for Mumbai-Pune expressways.**

Different locations on Mumbai Pune expressway (MPE) were selected for study purpose and the data were collected at total seven basic section locations. The effects of horizontal and vertical curves and gradient are not considered in this study, thus the locations selected were free from these elements. The locations were free from any nearby bottlenecks and have uniform roadway width throughout the study section. There are four locations on MPE (10.5 metres roadway width. Pictures of the selected locations on MPE are shown in Figure 1.

Video data were collected during day time with good visibility, dry pavement conditions and on clear weather days. Multiple cameras were installed at required height above ground level so as to get a clear view of minimum 100 m roadway length. Data were extracted by playing the videos frame by frame using Avidemux software. The minimum accuracy of the above-mentioned software is 0.04 (which mean 25 frames per sec/0.04 second of accuracy per frame). More 88uuthan 10 hours of video data were used for this study. Longitudinal trap of various lengths (31.5m, 40.5m, 45m, 50m,100m) less than 100m on road segment was considered for measuring speed of individual vehicle types. Volume, vehicle category, timestamps of individual vehicle at entry and exit of the trap length, speed of individual vehicle, entry time and exit time lane number as well as complete lane changing of vehicle from one lane to another lane within the trap length was extracted. Speed was measured by taking time difference of corresponding timestamps of vehicle front wheel crossing the entry and exit line of the trap length considered for study purpose.

## 4. PRELIMINARY DATA ANALYSIS

The traffic composition of different locations has been shown below. The table shows that majority of the proportion of traffic consists of passenger cars (PC), sport utility vehicles (SUV), trucks and bus, whereas the proportion of light commercial vehicle (LCV) is less than 6% of the traffic stream. Heavy vehicles (HV) like bus, truck generally stick to the outermost lane whereas cars and SUVs occupy the lane closer to median. Traffic composition of different locations of data collection of Mumbai-Pune expressway (MPE) is tabulated below in Table 1.

**Table 1 Details of traffic composition at various locations on Mumbai-Pune expressway (in percentage)**

| Expressway | Location | Direction | Car | SUV | HV (Bus and Truck) | LCV |
|---|---|---|---|---|---|---|
| #MPE | Near Chikale bridge | Towards Mumbai | 61.98 | 17.84 | 18.02 | 2.16 |
| | Near Chikale bridge | Towards Pune | 58.47 | 24.21 | 15.50 | 1.82 |
| MPE | Near Bhattan tunnel | Towards Mumbai | 69.88 | 6.02 | 20.48 | 3.62 |
| MPE | Near Railway bridge | Towards Pune | 55.11 | 10.36 | 32.26 | 2.27 |

*#MPE- Mumbai Pune expressway*

Relative speed ratio (RSR) method has been adopted for determining the critical headway to separate platooning. Relative speed ratio (RSR) is the absolute value of 1 minus ratio between speeds of two consecutive vehicles. So, when the speeds of the two vehicles are same, RSR will be 0. This method has the advantage of normalising the data by reducing variability in speeds and their standard deviations. Evaluating the mean and/or standard deviations of the absolute relative speeds for different headway ranges of vehicles combinations (PC-PC, PC-HV, HV-HV) and taking the mean of the obtained critical headways. As headway increases, the increase in relative speed ratio happens till it reaches a stable point. The point of headway where the relative speed stabilise is termed as critical headway.

**Table 2 Preliminary traffic data details**

| Expressway | Location | Direction | Vehicle composition in % | | | | | Directional Flow (vph) |
|---|---|---|---|---|---|---|---|---|
| | | | Car | SUV | Bus | Truck | LCV | |
| MPE | Near Chikale bridge | Towards Mumbai | 64.3 | 23.5 | 3.4 | 7.3 | 1.4 | 1792 |
| | Near Chikale bridge | Towards Pune | 57.2 | 25.5 | 4.0 | 11.2 | 2.1 | 1477 |
| MPE | Near Bhattan tunnel | Towards Mumbai | 55.3 | 26.7 | 4.7 | 12.2 | 1.1 | 389 |
| MPE | Near Railway bridge | Towards Pune | 54.4 | 31.5 | 0.9 | 10.0 | 3.2 | 1349 |
| NORR | Near Gachibowli | Towards City | 65.4 | 19.1 | 1.4 | 11.8 | 2.2 | 1315 |
| AVE | Road over bridge (Location 24) | Towards Vadodara | 71.9 | 18.5 | 3.4 | 6.1 | 0 | 418 |
| | Road over bridge (Location 8) | Towards Ahmedabad | 55.5 | 24.4 | 8.9 | 2.2 | 8.9 | 135 |

## 5. LANE UTILIZATION

To understand the traffic behaviour on expressways, a better understanding of lane utilization by vehicles is needed. As lane utilization affects the platooning behaviour of vehicles significantly. Lane utilization plots in Figure 2 shows the percent of individual lane utilization by vehicle with reference to total traffic flow. The x-axis is the directional traffic volume obtained by converting 5-min counts. From the Figure 2 it is clearly shown that, lane 1 (median lane) is most utilised followed by lane 2 (middle lane) and lane 3 (shoulder lane).

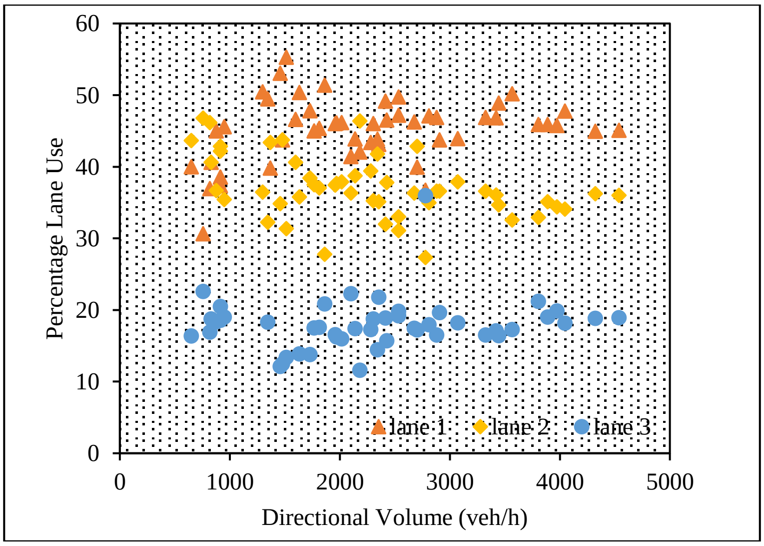



**Figure 2 Lane utilization distributions versus directional volume.**

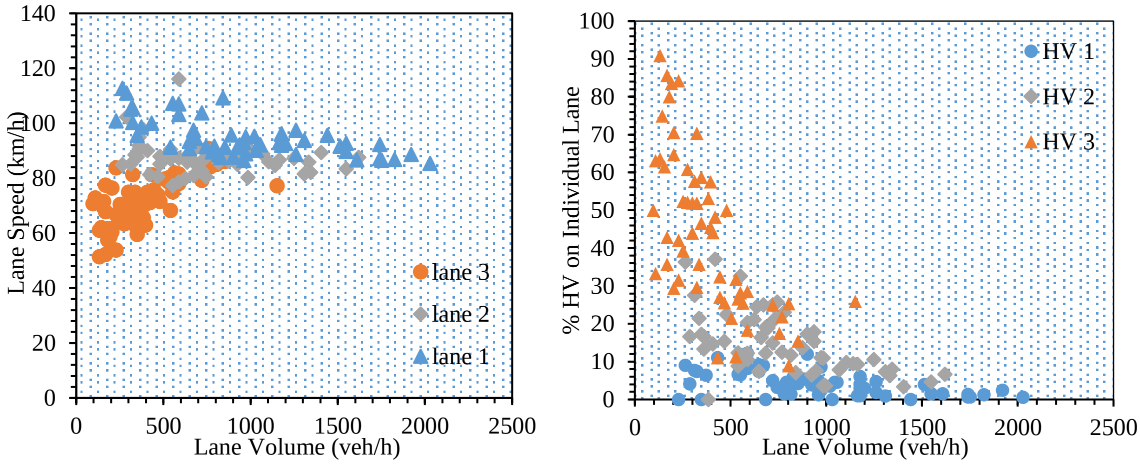



**Figure 3 Speed flow relationship and HV percentage vs flow for individual lane.**

Speed variability among lanes is significant. This is shown in Figure 3, where speed flow curves for individual lane are plotted. In Figure 3, HV1, HV2, HV3 presents Heavy vehicle percentage on lane 1, lane 2 and lane 3 respectively. The highest values were noted for lane 1(lane nearer to median) and the lowest values for lane 3 (shoulder lane) for expressway. This trend can be supported by second figure in Figure 3 where it can be clearly shown that HV percentage is maximum on leftmost lane as compared to other lanes, which could possibly result in low average speed. Higher occupancy of HV results less flow on it. Rear following vehicles used to avoid leftmost lane because of safety concerns and limited visibility caused by HVs. As we see from Figure 3, that significant speed variability and vehicle size variability exists among lanes. This in terms causes platooning on expressways because slow moving vehicles such as heavy vehicles hinder the normal high-speed moving vehicles flow on roads.

## 6. METHODOLOGY

Several techniques were used to identify the critical headway for separation of platooned vehicle and free vehicles. The initial criteria for segregation of platoon from free vehicles in traffic flow is critical headway. Since the free vehicles and following vehicles on highways indicate the service quality on highways, it's important to define and determine critical headway. Different methods used for calculation of critical headway. A group of vehicles moving in the same lane at a closer headway and having minimum variation in speed. In a platoon, vehicles are influenced by one another. It was observed that the platoon portions are not a stable portion of traffic as on expressways the platoon used to continue for 40 to 50 meters (which was considered as a trap length for data extraction and after that it used to disperse quickly as the slow-moving vehicles used to do overtaking.

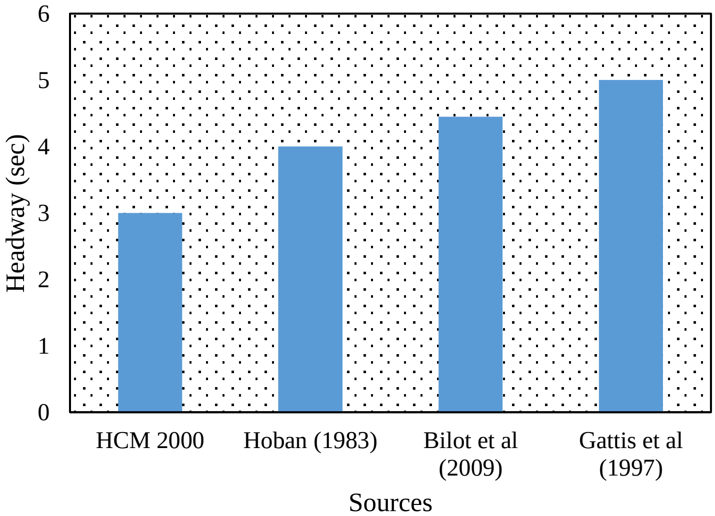



**Figure 4 Critical headway values for distinguishing platooned vehicles**

Al-Kaisy and Durbin [19] suggested a critical headway of less than 5 second for which all platooned vehicles can be captured. But the threshold value of 5 second might capture a portion of free flow vehicles as well. Hoban [18] considered the threshold value of 4 second to capture the platooned vehicles without diluting the results with free flow vehicles on roads. Different thresholds of time, varying from 2 to 5 second has been widely used in the past for platoon identification.

### 6.1 Determination of critical headway

Various techniques are used to determine critical headway. All the methods are described below and the most suitable method is outlined. In this paper, the task is to study the various headway data separately and the relationship between volume level on platooning and headway distribution.

1. Standard deviation of all speeds.
2. Standard deviation and number of platoon ratio.

Sample data are examined for platoon headways of 1.5, 2, 2.5, 3, and 3.5 sec. the initial comparisons are made on the basis of platoon number per hour, platoon size (number of vehicles with successive headways less than the platoon headway).

### Indicators of Variability of Speed

An ideal indicator of speed should ideally be a diatonic function of the supply headway, reaching its minima at the critical headway. Figure 5 gives an idea about the basic idea behind finding the platoon headway for the data obtained from Mumbai-Pune expressway. The qualitative variation of an ideal indicator of variability with the supply headway. This is the basic idea used for determining critical headway.

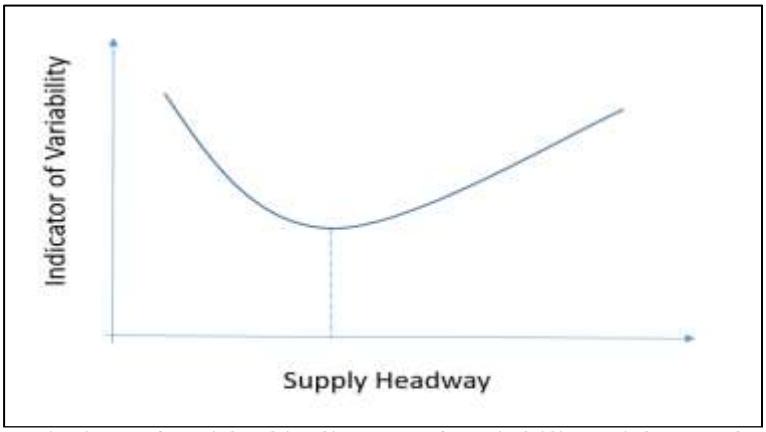
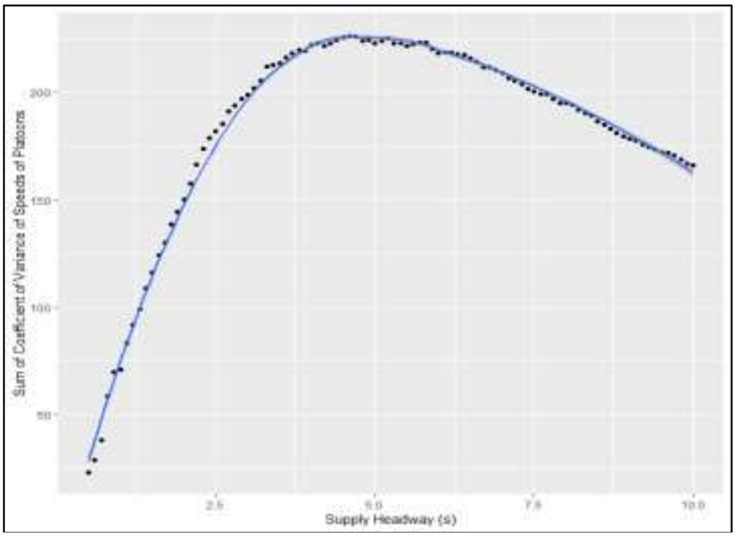



**Figure 5 Variation of an ideal indicator of variability with supply headway**

### 6.1.1 Sum of Coefficient of variation of all platoons

We start off with the sum of coefficient of variation of speeds of all platoons as our indicator of variability.

$$IoV = \sum \frac{std(v)_i}{v_i}$$



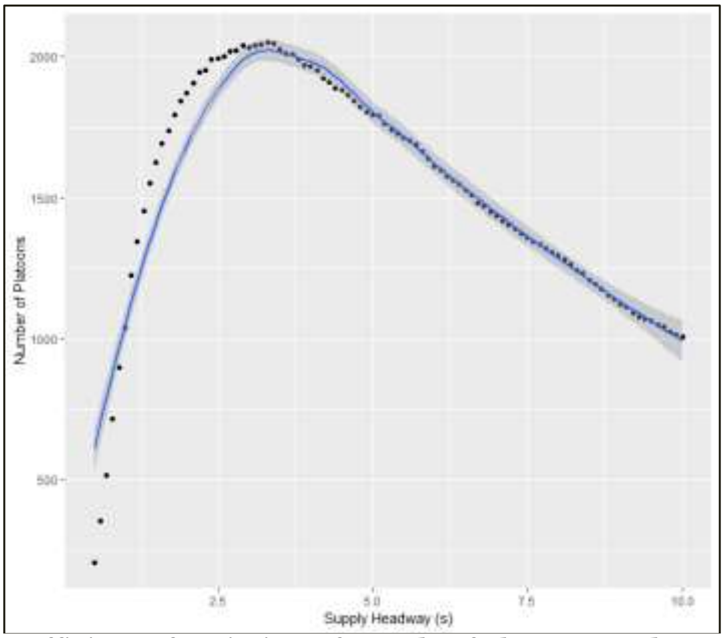



**FIGURE 6 Sum of coefficient of variation of speeds of platoons and number of platoons vs supply headway**

Figure 6 shows the variation of the proposed IoV with the supply headway, we see an increase in the sum of coefficient of variation and after a point it starts falling. This happens because as the supply headway changes, the number of groups of vehicles labelled as platoons also changes, until a given value increasing the supply headway increases the number of platoons, but as the supply headway exceeds that value, the number of platoons starts coming down, which makes sense cause if the critical headway is infinite, then all the vehicles are just part of one huge platoon. The sum of the coefficient of variations of platoons will be higher when the number of platoons is higher, and will fall when the number of platoon falls. This does not seem like a good IoV as it fails to normalize the effect of the change in number of platoons due to the changing supply headway.

### 6.1.2 Average Coefficient of Variation of a Platoon

To deal with the changing number of platoons, we can try calculating the average coefficient of variation i.e. the coefficient of variation per platoon can be calculated using equation 1.

$$IoV = \frac{\sum \frac{std(v)_i}{v_i}}{N} \quad (1)$$

Figure 7 shows the plot of the mean Coefficient of Variation of Speeds of Platoons with the

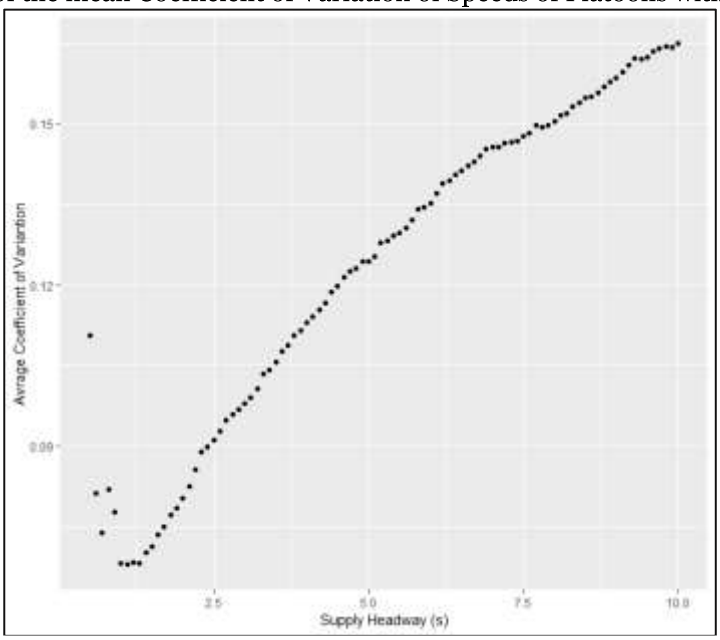



**Figure 7 Average coefficient of variation of speeds of platoons**

Supply Headway, the plot also shows the Average Standard Deviation vs the Supply Headway for comparison. Both the plots show a clear minimum. The average variation in speeds at the minima is as low as 7%. This seems like a plausible IoV. The critical headway according to this fall around 1.3 seconds.

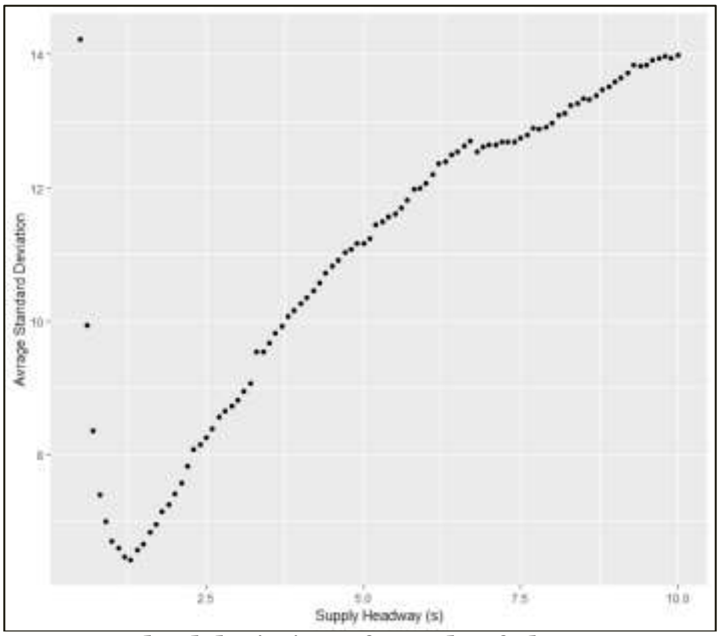



**Figure 8 Average standard deviation of speeds of platoon vs supply headway**

These figures illustrate the variability of the indicator when altering the platoon's speeds and modifying the average coefficient of speed variation.

### 6.1.3 Average Coefficient of Variation of a Platoon per Vehicle

It can be contended that the coefficient of variation fluctuates with the number of vehicles in a platoon, with larger platoons likely exhibiting a higher coefficient of variation. Therefore, an alternative Index of Variation (IoV) that normalizes the influence of the platoon's size was suggested. This could be represented as the average coefficient of variation of vehicle speeds per vehicle within the platoon.

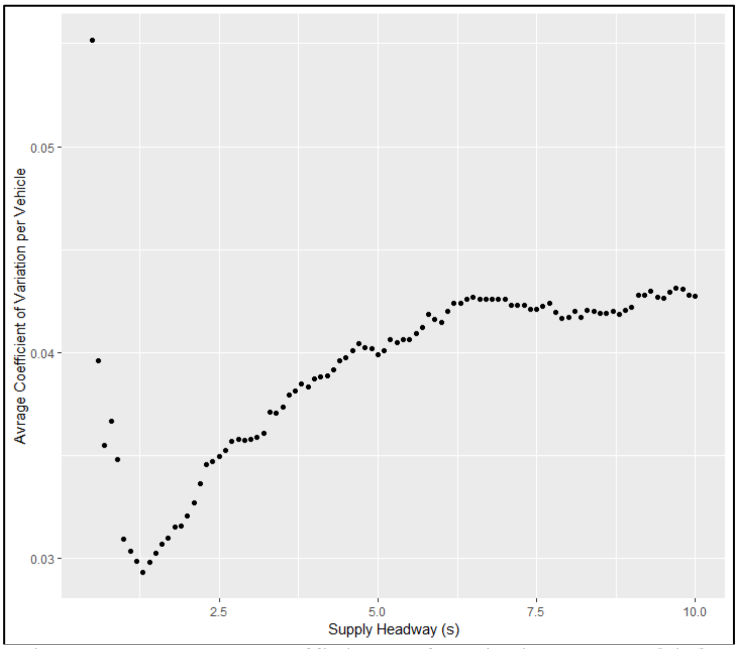



**Figure 8 Average coefficient of variation per vehicle**

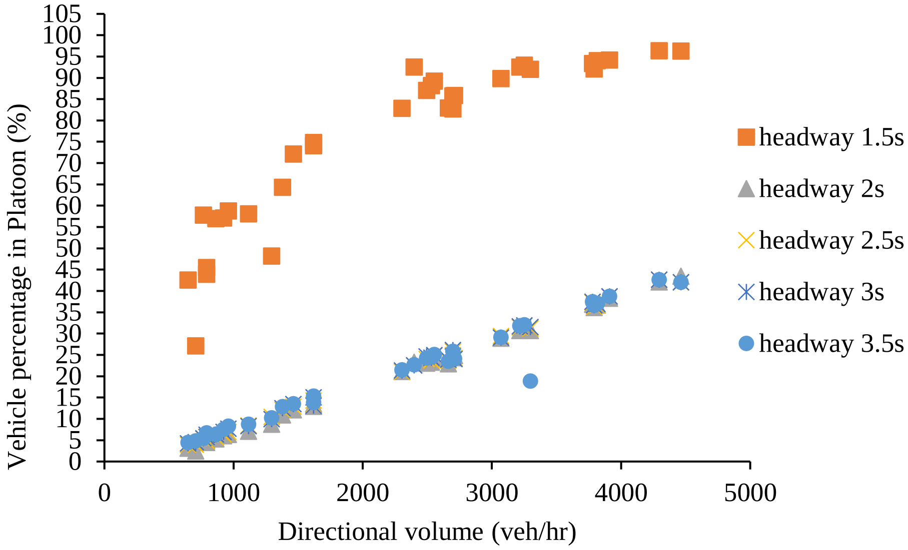
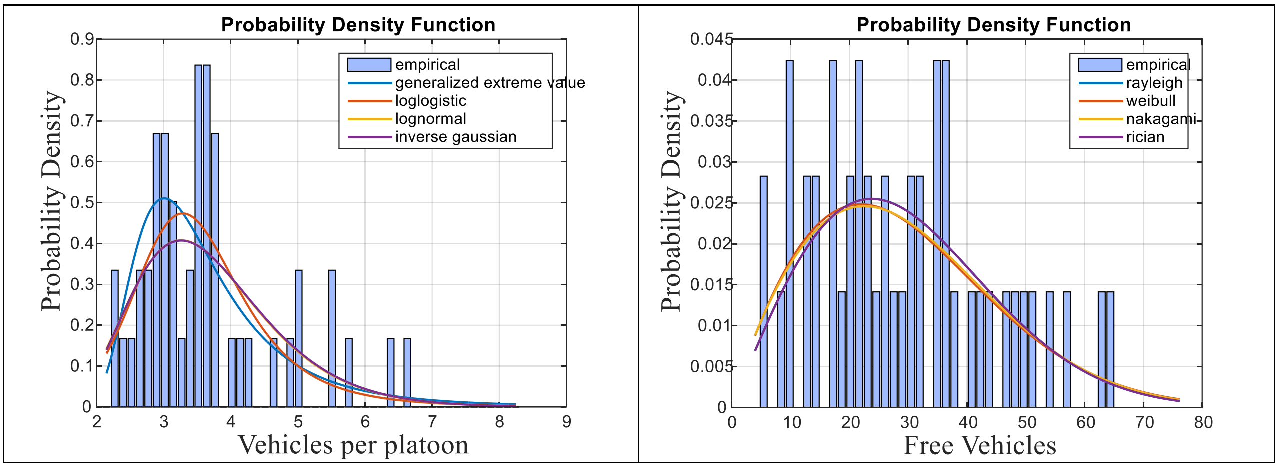



**Figure 9 Platoon percentages estimated using different headway threshold**

## 7. Platoon Analysis

A platoon is a group of vehicles trailing one or more leader vehicles, where the following vehicles must adjust their speed, acceleration, or spacing relative to the leader vehicle. In a platoon, the vehicle at the front is referred to as the leader vehicle. There can be one or multiple leader vehicles. Consequently, a platoon can be categorized into two types: platoon leaders and platoon followers. On expressways, due to varying lane usage, heavy vehicles tend to occupy the shoulder and middle lanes. The slower acceleration rates of heavy and slow-moving vehicles initiate the formation of vehicle platoons.




| (a) Fitting of vehicles per platoon | (b) Fitting of free vehicles |
|---|---|

**Figure 10 Fitting of platoon parameters**

Platoon characteristics on expressways are quite different as compared to two lane highways as opportunity for lane changing and overtaking are quite common on expressways. Figure 10 demonstrates that platooning is occurring when volume range is low till a certain volume range, then again decreasing when volume is increasing. Somehow the curve is coming as inverse parabolic curve which shows the platoon rate scatter mostly at medium volume range. This is due to presence of Heavy Vehicle in traffic. Most of the higher volume of platoon rate occur at lower presence of HV but medium range of platoon rate occur when HV presence is more. Fitting the trend for the obtained curve by using MATLAB R2015b, equation 1 comes like:

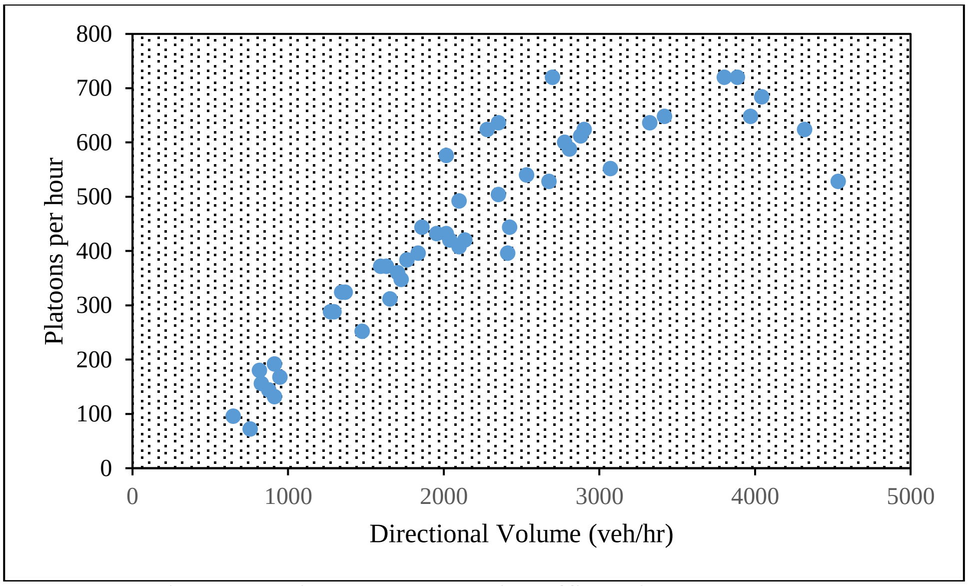



**Figure 11 Platoon rate and traffic volume on MPE**

$$platoon/hr = 340.53\ln(volume) - 2144.1 \quad (1)$$

Where volume = traffic flow in vehicle/ hour

$R^2$ =0.8767

Equation 1 can be used for predicting platoon rate on six lane divided expressways. Figure 6 shows that average platoon size increases with respect to traffic volume. The relationship between average platoon size and traffic volume is nearly close as exponential function. Average vehicles per platoon increase rapidly as volume increases, then increases less rapidly as volume increases due to less headway maintained by vehicle in high traffic volume as joining of more vehicle in platoon. Fitting the data into a best fit curve by using MATLAB R2015b the equation 2 comes like:

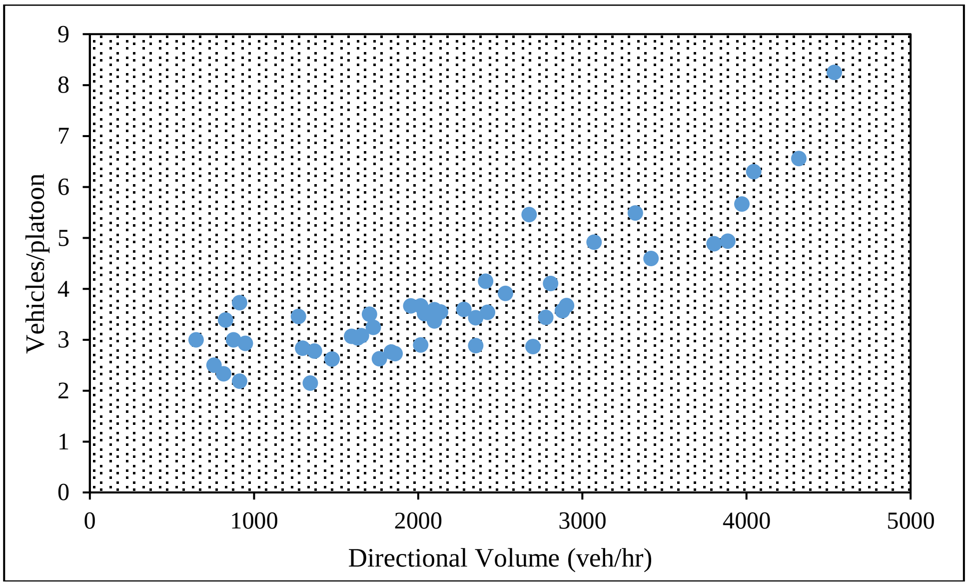



**Figure 12 Average platoon size and traffic volume on MPE**

$$vehicles/_{platoon} = 2.0897e^{0.0002volume} \quad (2)$$

Where volume = traffic flow in vehicle/ hour

These two equations (1) and (2) can be used for calculating platoon rate and vehicle per platoon on a 6 lane divided expressways if the traffic volume per direction is known.

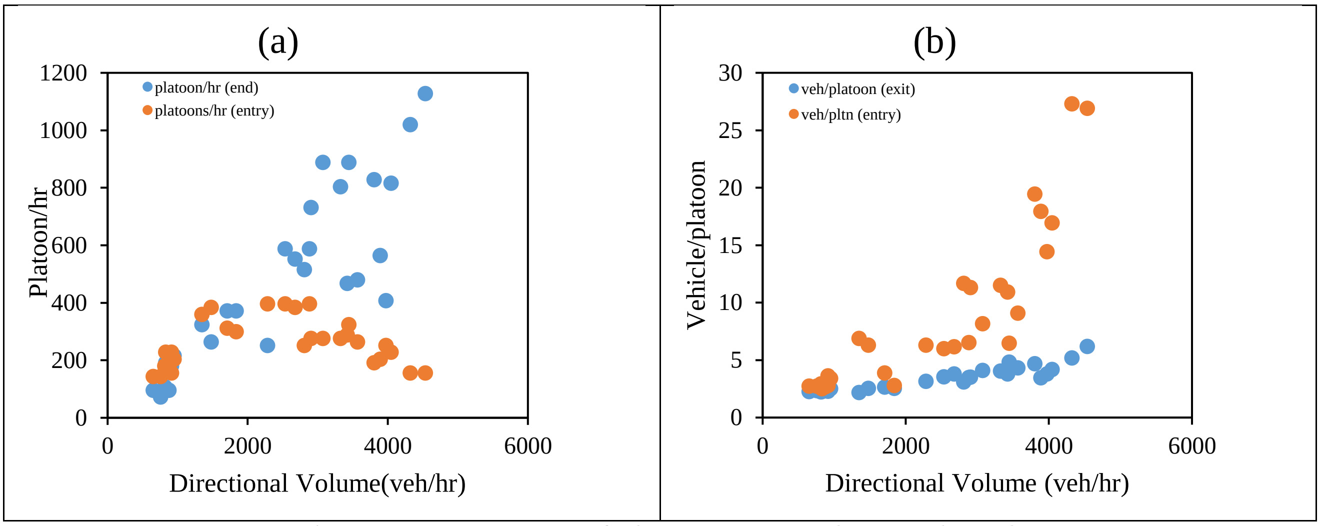



**Figure 13 Movement of platoon across the trap length**
**(a) No of platoon/hr, (b)vehicles/platoon forming at entry and exit of trap length**

Platoon rate as well as vehicle per platoon are compared in figure 13, the main reason behind the comparison is to see the behaviour of platoon motion in between the trap length.

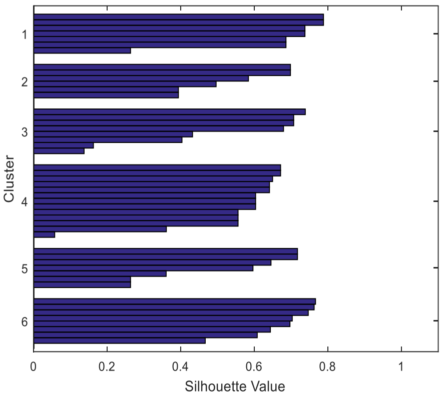
### 7.1 K- means clustering

**Fuzzy c-means**

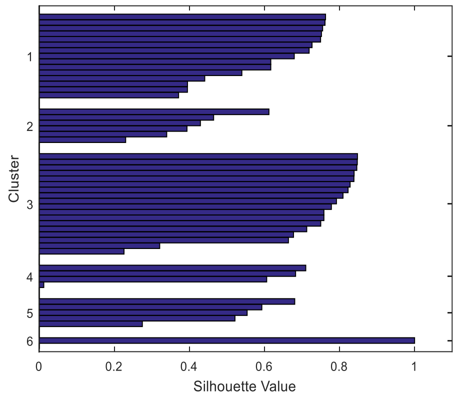
The basic idea proposed by Zadeh [15] is to divide the points to the group where its similarity exists. Data points can be partitioned into a specific number of overlapping natural groups, i.e., fuzzy clusters, with each data point in each cluster to some degree specified by a membership value. Fuzzy-c means adopted the fuzzy set theory, in which the data point is assigned to more than one cluster. The basic difference between fuzzy-c means and k-means clustering is that, in k-means cluster objects belong to only one cluster whereas in fuzzy c-means cluster considers each object a member of every cluster. Grouping of a set of objects into different groups in a manner such that the objects in the same group are more similar to each other as compared to other groups. Cluster makes segment of collection of objects (sometimes also called as data, individuals or observations) into different subsets or clusters, in such a way that those within the cluster are more closely related to each other than objects assigned to another clusters or groups.
Basic logic behind k-means clustering:
Let's take a set of n points ( $x_1, x_2, x_3 \ldots . x_n$) of set X and the $K$ clusters be presented by ( $K_1, K_2, K_3 \ldots . K_n$)
Step 1. Choose k points from set $K$ randomly as initial centroids.
Step 2. Assign points ( $x_1, x_2, x_3 \ldots . x_n$) to cluster of k points
Step 3. From K clusters by assigning each data point to its nearest centroid.
Step 4. Recompute the centroid for each cluster until centroid does not change (step 2).
This work presents a methodological approach which uses clustering technique to segregate level of service on expressways in India.

### 7.1.2 Silhouette plotting for clusters

In the present study, six number of clusters is chosen for the LOS analysis as reference to HCM 2010, Indo-HCM 2018 and other similar researches carried out who have taken six number of ranges for defining level of service of road systems. For cross checking silhouette plot is plotted and silhouette values are obtained. A silhouette value of greater than 0.71 is reported to form a strong clustering structure. Silhouette values ranging from .57 to .67 are coming for this study.




(a) Platoon number




(b) Vehicles per platoon

**Figure 8.12 (a), (b) Silhouette plot with six number of clusters for various platoon parameters**

In this study, the level of service (LOS) on expressways is classified based on platoon-related parameters, including the number of platoons, the number of vehicles within each platoon, and the count of free vehicles. Table 3 presents the LOS ranges concerning these parameters. The number of platoons, vehicles per platoon, and free vehicles collectively determine the service quality experienced by road users on expressways.

**Table 3 LOS values by using platoon parameters**

| Level of Service (LOS) | Platoon number |
|---|---|
| A | 6-16 |
| B | 21-29 |
| C | 30-37 |
| D | 41-46 |
| E | 48-54 |
| F | 57-60 |

| Level of Service (LOS) | Vehicles/platoon |
|---|---|
| A | 2-3 |
| B | 3.2-3.8 |
| C | 3.9-4.1 |
| D | 4.5-4.9 |
| E | 5.4-6.2 |
| F | >8 |

| Level of Service (LOS) | Free Vehicles number |
|---|---|
| A | 53-60 |
| B | 61-67 |
| C | 69-73 |
| D | 74-76 |
| E | 78-82 |
| F | 84-87 |

## 8. APLICATIONS AND CONCLUSIONS

Traffic behaviour on expressways significantly varies across lanes and there is need of development of models for individual lane for predicting speed, density and flow for individual lane and the models can give a better and more reasonable representation of traffic scenarios on expressways. This paper investigates various ways of determining platooning headway for Mumbai-Pune expressway in India, where frequent platoons are observed. Average coefficient of variation within a platoon method gave a platooning headway of 1.3 second for the collected data from MPE. Different parameters of platooning are used for defining LOS on expressways. LOS defined by platoon parameters will be helpful in determining level of service on expressways as present level of service mainly focuses on density which has some drawback.

Density measures the number of vehicles per kilometre, which may not fully capture the traffic behavior patterns over a given stretch of road. In contrast, using metrics like platoon rate and vehicles per platoon to assess the level of service provides a more accurate representation of actual traffic conditions, whether for short segments or longer road stretches. This study will assist in establishing traffic management policies for expressways in India and similar countries, aiming to maintain a better level of service on the roads.

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