

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015,
Delft, The Netherlands

Discharge headway model for heterogeneous traffic conditions

Sanjay Radhakrishnan, Gitakrishnan Ramadurai*

IIT Madras, Chennai 600036, India

Abstract

Discharge headway is the headway between successive vehicles negotiating an intersection during the green time of signal operation. It is an important parameter in signal operations and analysis since estimation of parameters such as saturation flow and capacity of an intersection depend on it. Although there have been several studies on discharge headway in homogeneous traffic conditions, there are only a few studies on discharge headways in heterogeneous traffic. This study examines the factors affecting discharge headway under heterogeneous traffic conditions which is characterized by mixed vehicle composition and lack of lane discipline. A novel method to measure headways in such cases is proposed here.

To get individual vehicle headways, each lane is divided into multiple strips. The width of a strip is approximately equal to the width occupied by a motorcycle. The headways of vehicles in each strip are measured separately and used for analysis. Data collection for the study was carried out at signalized intersections in Chennai, India. Data was collected for one approach at all intersections. From the data collected, headways of individual vehicles were measured. Linear mixed effect regression was used to model discharge headway. The effect of vehicle type, lateral position on roadway, and green time on discharge headway were modeled. From the regression analysis, it was found that all these factors had significant impact on discharge headway. The discharge headway model proposed in this study could be used for obtaining saturation flow rates and capacity at signalized intersections under heterogeneous traffic conditions.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of Delft University of Technology

Keywords: Discharge headway; Heterogeneous Traffic; Signalized intersections; Linear mixed regression

1. Introduction

Intersections are a vital part in an urban transportation network. The main traffic parameters at a signalized intersection include discharge headway, saturation flow, and capacity. Among these, discharge headway is an important one since it is used to determine other parameters such as saturation flow and start-up lost times at intersections. These two parameters have in turn been used in determining optimal signal timings. Inaccuracies in discharge headway values would lead to non-optimal signal operations. Several studies have been carried out on discharge headway - on factors affecting it, on distribution followed by headway, and on determination of other traffic parameters from discharge headway. Most of these studies were done for homogeneous traffic which is characterized by lane disciplined

* Corresponding author. Tel.: +91-44-2257-4298 ; fax: +91-44-2257-4252.

E-mail address: gitakrishnan@iitm.ac.in

movement and cars were the predominant vehicle type present. Several Asian countries including India have heterogeneous traffic lacking in lane discipline. This study focuses on understanding discharge headway of heterogeneous traffic.

While discharge headway has been studied for over seven decades, even recently studies have examined fundamental questions such as the existence of a saturation headway (Radhakrishnan and Mathew (2011); Remias et al. (2013)). Heterogeneous traffic conditions and the absence of lane following provide significant challenges to the study of discharge headways. For example, consider a single lane with two motorized two-wheelers travelling side-by-side which is followed by a car. How would the headway for the car be defined? The traditional definition of headway as the time gap between successive vehicles in a lane cannot be applied here.

In this paper a novel method of headway definition is proposed. The roadway width is divided into multiple strips. A strip is narrower than a lane just wide enough to accommodate no more than one two wheeler at a time. Headway is measured in each strip separately. Data is collected from three different intersections. At one of the intersections data is collected for morning and evening peak periods. Headway data shows significant variability. Regression models are developed for discharge headway with vehicle type, lateral position along the road width, and the green time period as explanatory variables. To better capture the variability of headway a mixed-effects model is also developed. The use of strips to more accurately and meaningfully measure headway is a fundamental contribution of the present work. This is also the first attempt, to the best of our knowledge, of developing a mixed-effects model for discharge headways.

The rest of the paper is organized thus: the next section provides an overview of literature in the area. While the research is over seven decades old, the emphasis here is on relevant and recent work only. Data collection and extraction process are described next. The analysis of data including the estimated models are presented in the fifth section followed by a concluding section.

2. Literature Review

Discharge headway at a signalized intersection can be defined as the time interval between two successive vehicles on a lane crossing the stop line at an intersection during the green time. Greenshields et al. (1947) was one of the first studies on discharge headway in which he reported average headways for the first five vehicles of the queue. Carstens (1971) reported the average starting delay for vehicles in queue as 0.75 s and average headway spacing for straight moving cars as 2.29 s per vehicle. Moussavi and Tarawneh (1990) conducted studies on departure headways at signalized intersections in Nebraska and concluded that departure headways show high variability for different intersections possibly because of the different traffic and geometric conditions prevailing there. They also came up with a set of values for departure headway of first seven queue positions. Bonneson (1992) developed a model for discharge headway at signalized intersections based on driver reaction time, driver acceleration, and vehicle speed. His model showed that a minimum discharge (saturation) headway is reached only after eighth or ninth queue position. Al-Ghamdi (1999) conducted a study on discharge headway at intersections in Riyadh, Saudi Arabia. He observed that it is not reliable to use discharge headway values from other countries in Saudi Arabia due to changes in factors such as driver behaviour and intersection geometry, and came up with average headway values for different queue positions.

Several other studies have come up with distributions for discharge headways. Jin et al. (2009) studied the departure headways at signalized intersections. They found that distributions of departure headways at each position in queue follow a log-normal distribution except the first one. A car-following model was also proposed to explain this behavior which can be used for intersection capacity analysis and traffic control. Liu et al. (2011) introduced a hazard based model to analyze the first discharge headway of queuing vehicles. The model has been developed on the basis of data collected from Beijing and it was found that the first discharge headway is dependent on vehicle type and complexity of intersection and any other disturbance to the vehicle movement will further increase the discharge headway. Wu et al. (2010) studied departure headway distributions. Their study revealed that for modeling headway data, log-laplace distribution model is suitable at free flow conditions and log-logistic model during peak hours. Yin et al. (2009) also arrived at similar conclusion about fitting headway distributions to headway data for free-flow state and congested state. Their findings include that headway data follows log-normal distribution when traffic is in free-flow state and

log-logistic distribution when traffic is congested. Rossi and Gastaldi (2012) also studied about the distributions for time headway data for rural two lane two-way roads.

Few studies on saturation headway/flow carried out in India for heterogeneous traffic include those of Maini and Khan (2000), Arasan and Koshy (2005), and Arasan and Vedagiri (2006). Maini and Khan (2000) conducted a study on discharge characteristics of heterogeneous traffic at signalized intersections in two Indian cities - Baroda and New Delhi. They determined clearing speed of vehicles from intersection and concluded that clearing speed does not vary significantly with vehicle type and vehicles move as a single platoon at intersection and those with higher performance are affected by those with lower performance. Arasan and Koshy (2005) suggested a method for modeling heterogeneous traffic flow by simulation with vehicles of wide ranging characteristics. The model was validated and found to replicate traffic without lane discipline and could be used for further studies on heterogeneous traffic. Arasan and Vedagiri (2006) applied a simulation model to estimate saturation flow to study the effect of road width on saturation flow under heterogeneous traffic conditions. It was found that there is a significant increase in saturation flow with increase in road width. Radhakrishnan and Mathew (2011) proposed a methodology to develop saturation flow model based on dynamic PCUs. PCU values are determined by minimizing the difference between ideal and observed flows using Thiels coefficient as the objective function and then saturation flow model is developed by regressing saturation flow in vehicles against the percentage of each class of vehicle.

From the review of existing literature, it is evident that discharge headway varies from place to place. It depends on factors such as vehicle type, intersection geometry, and traffic characteristics. Most of the studies were carried out on homogeneous traffic conditions where car is predominant and has lane disciplined movement. Few studies also reported the distributions followed by discharge headway as well as the average values of discharge headway for different vehicle positions in the queue. But with regard to heterogeneous traffic lacking in lane discipline, discharge headway is not well studied.

3. Data Collection

Data collection was done by video recording the traffic movement at three signalized intersections in Chennai, India. For measuring headway values, video camera should be oriented in such a way that the view of any vehicle is not severely obstructed by other vehicle. Video camera was mounted on high rise buildings/light posts in the vicinity of the intersection that provided a clear view of traffic movements. Video was recorded during the peak periods at the intersections. Location A is a signalized intersection on a six lane road. This intersection handles significant amount of traffic during the peak hours. The intersection connects three major roads and a service road. Among the three approaches, movement of traffic in only one approach was recorded. Video was recorded during morning (08:00-10:00am) and evening (05:00-06:40pm) peak hours at this location. Location B is an intersection that connects four approaches, all of which are divided arterials. Traffic movement in one approach during morning peak hour (09:00 to 10:00am) was recorded. Location C is an intersection with two major roads and two minor roads. Traffic movement in one of the major road sections was recorded during the morning peak hour of 08:00 to 10:00am. In all these intersections, policemen were manually controlling the signal timings depending on the traffic queue lengths.

4. Data Extraction

Time headway is defined as the difference in time when the front/back of a vehicle crosses a point in the road section and the time when the front/back of the next vehicle crosses the same point. Discharge headway can be defined as the time headway of vehicles that are discharging from an approach to an intersection when the signal is green. Time stamps of different vehicles crossing the stop line were obtained using the software MCME (Ramadurai, 2013). Five different classes of vehicles were analysed namely two wheelers (2W), cars, auto-rickshaws (3W), light commercial vehicles (LCV) and heavy motor vehicles (HMV). A reference point is chosen close to the stop line of intersection, with respect to which headway values are to be measured. When a vehicle passes this point, the vehicle type and the time stamp is recorded. The recorded data is subsequently post-processed to obtain the discharge headway.

4.1. Strip Headway

In India, two wheelers were found to advance through the gaps and move to the head of the queue. The arrangement of vehicles is hap-hazard at the start of green. When the signal turns to green, all these vehicles discharge together side by side very close to each other without any lane discipline. This makes it difficult to measure the headway values of vehicles since there will be more than one vehicle moving simultaneously through the road section. In-order to get a unique headway value for each vehicle, a new approach of strip headway is used for measuring headway values. It is based on dividing the whole road section into several longitudinal strips such that one strip width can accommodate only one motor cycle at a time. This ensures that on any given strip the headway is uniquely defined since there is utmost one leading/following vehicle. Thus headway values are measured for each strip separately. As the width of strip is equal to width of two wheelers, other vehicles will be occupying multiple strips at a time which results in multiple headways for same vehicle. Figure 1 (b) depicts such a scenario with h_1 and h_2 being the headways for the same vehicle. For addressing this problem and obtaining unique headway for each of the vehicles the following procedure is adopted. Firstly the headway data is aggregated based on elapsed green time at a level of 0.5 second. This is done to identify the multiple detections of same vehicles among different strips. Among the multiple values of headway, the smaller value indicates the presence of closer vehicle and it could be assumed that this closer vehicle will be affecting the movement of vehicle of interest more than other vehicle(s). Thus the smallest headway among multiple values is chosen (In figure 1 (b) this value will be h_1). Thus the entire data is reduced to data with each vehicle having a unique headway which is used for further analysis. From the available data, higher headway values (values greater than 8 seconds) are ignored and the remaining is used for data analysis. The width of road sections and the number of strips used for extracting data at location A, B and C are respectively 11m (10 strips), 7m (5strips) and 7m (5strips).

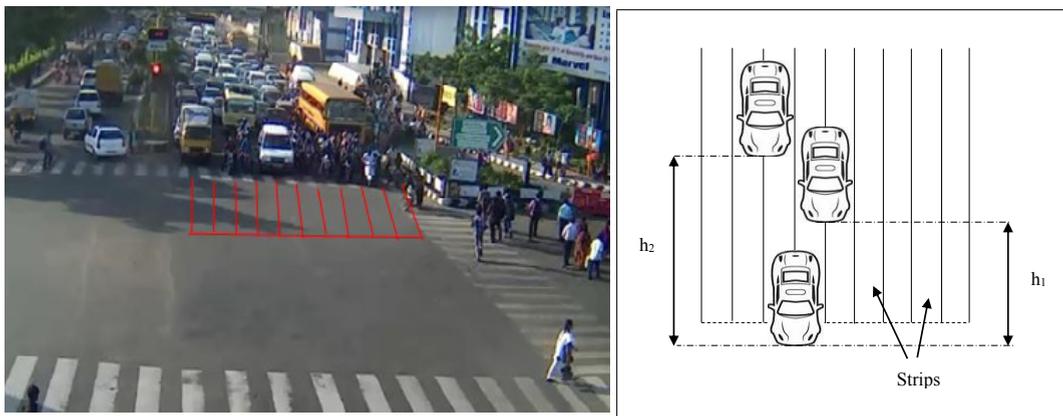


Fig. 1. (a) Data extraction stripwise, (b) Vehicle occupying multiple strips

5. Data Analysis

5.1. Understanding the Data

The analysis of the video data revealed that the traffic is heterogeneous with significant number of vehicles in all the vehicle classes considered. Figure 2 is a pie chart representing the vehicle composition for the selected study locations. Two wheelers constitute about half of the total vehicles in all locations. Next highest percentage composition is that of cars followed by 3W, LCV, and HMV. The higher composition of two wheelers indicates that two wheelers will have significant impact on the discharging vehicles from signalized intersections. Unlike passenger car only traffic, here two wheelers will move through the available gaps and fill the vacant areas in the queue waiting for discharge. This will lead to change in behaviour for the discharging traffic and their headway values which is being addressed through this study.

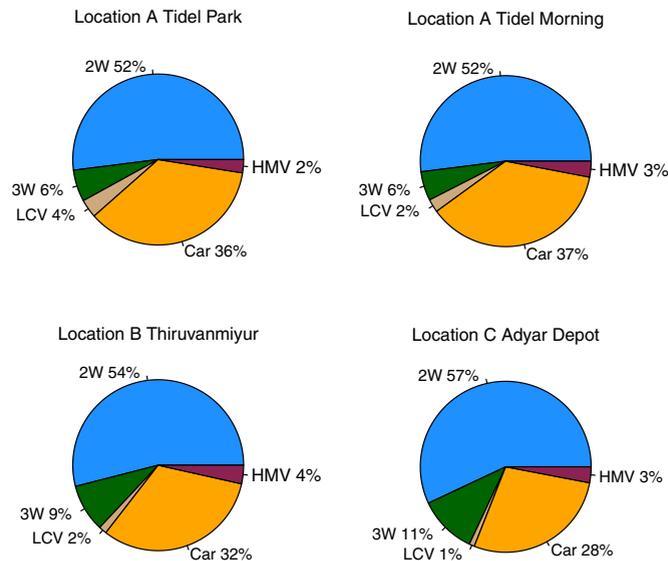


Fig. 2. Pie chart showing vehicle composition

Figures 3 (a) and 3 (b) are the boxplots of discharge headway values with respect to vehicle class and lateral position of vehicle. It can be observed that both these variables have a significant effect on discharge headway.

5.2. Factors affecting discharge headway

For better understanding and modelling of discharge headway, finding the factors affecting it is essential. Many earlier studies have brought out the variables on which discharge headway depends. Bonneson (1992), Liu et al. (2011), and Tong and Hung (2000) have come up with models for discharge headway under different conditions. Few other studies like Moussavi and Tarawneh (1990), Al Ghamdhi (1999), Greenshields et al. (1947) and Carstens (1971) analysed the dependence of intersection geometry, driver behaviour, traffic characteristics on discharge headway. Previous studies on discharge headway suggest the need for development of explicit model for different countries according to the traffic conditions prevailing there. This study is intended to analyse the effect of factors such as vehicle type, lateral position of vehicle on the road section and green time (time interval since when traffic signal turned green) on discharge headway for data collected in Chennai, India. The next section describes the process of obtaining the relationship between the above variables using linear regression.

5.3. Linear Regression

The following linear model was estimated to represent the discharge headway (equation 1).

$$Headway = \beta_0 car + \beta_1 auto + \beta_2 lcv + \beta_3 hmv + \beta_4 time + \beta_5 median + \beta_6 nearerb \quad (1)$$

Here *Headway* represents discharge headway, *car*, *auto*, *lcv*, *hmv*, are 0-1 indicator variables for cars, auto rickshaws, light motor vehicles and heavy motor vehicles respectively. Variables *median* and *nearerb* represent the lateral position of the vehicle on the basis of strip number. Variable *median* is formed by combining the strips 1, 2 and 3 (closest to the median). Variable *nearerb* is formed by combining the strips 8, 9 and 10. Finally variable named *time* is measure of green interval time. All the variables are explained based on the data from location A. Variables representing the lateral position such as *median*, *nearerb* will change for data from other locations are used as the number of strips in each location is different.

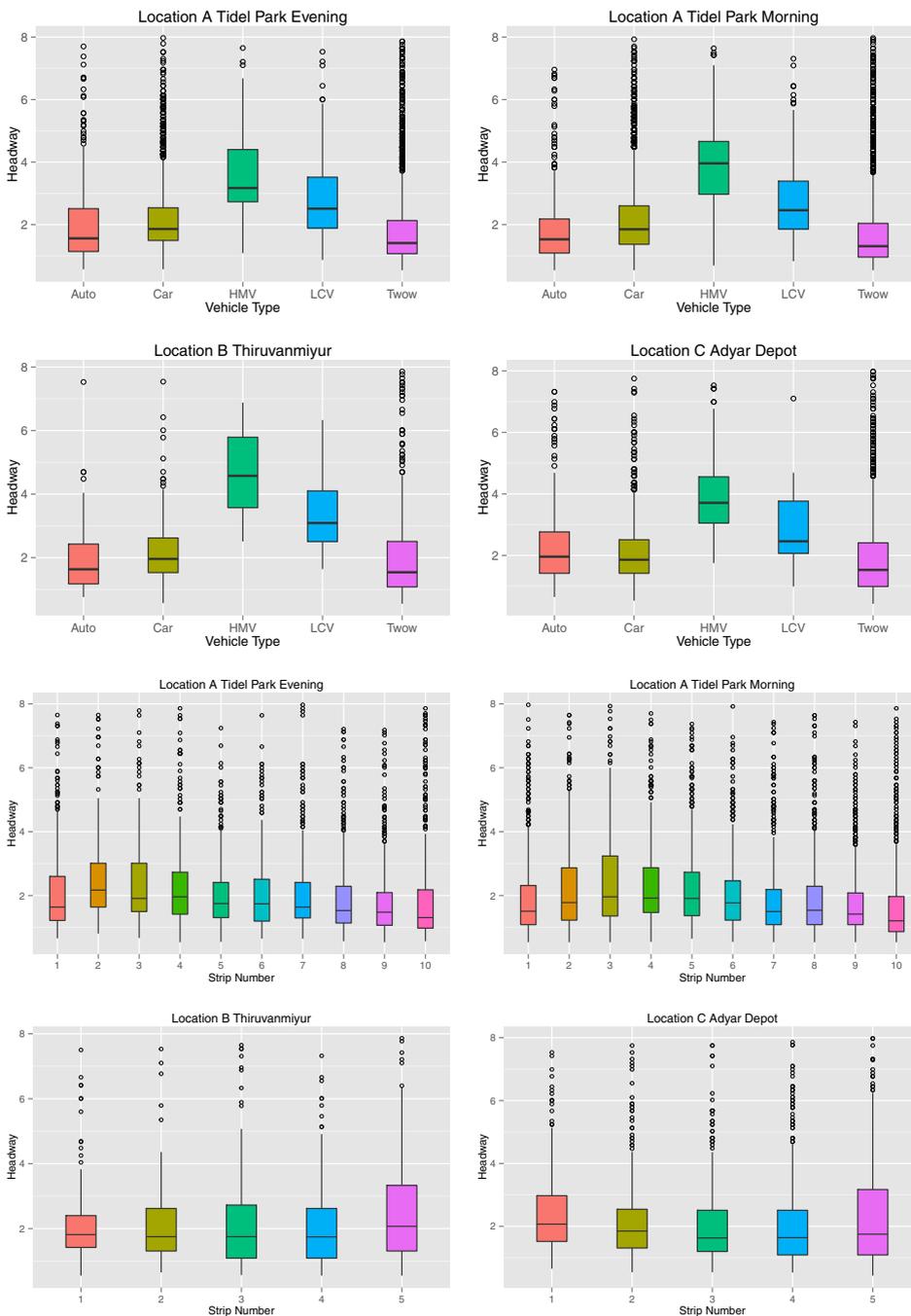


Fig. 3. Boxplot of headway with respect to (a) Vehicle type (b)Strip Number

To study the effect of following vehicle on the discharge headway of leading vehicle, the following variables were used: *twowf*, *carf*, *autof*, *lcvf* and *hmvf*. These are 0-1 indicator variables indicating whether the following vehicle is a two wheeler, car, auto-rickshaw, light commercial vehicle and heavy motor vehicle respectively. All the variables were used for data from different locations to estimate the coefficients. Insignificant variables were discarded and

regression analysis is redone to get the estimates of the remaining variables. The same model specification is used for data from different study locations.

Table 1. Linear regression model output.

Variable	Location A Tidel Evening		Location A Tidel Morning		Location B Thiruvanniyur		Location C Adyar Depot	
	Estimate	p value	Estimate	p value	Estimate	p value	Estimate	p value
Intercept	1.72	<2E-16	1.75	<2E-16	1.81	<2E-16	1.45	<2E-16
car	0.26	1.9E-11	0.39	2E-16	0.19	0.06	0.18	0.008
auto	0.20	0.007	0.15	0.02	-0.11	0.48	0.30	8E-04
lcv	0.91	<2E-16	1.03	<2E-16	1.35	7E-04	0.90	0.003
hmv	1.83	<2E-16	2.21	<2E-16	2.67	<2E-16	2.00	<2E-16
time	0.002	9E-09	0.0007	0.002	0.004	0.002	0.007	5E-13
median	0.24	1E-07	0.05	0.14	-0.17	0.09	0.17	0.02
nearerb	-0.15	3E-04	-0.21	2E-10	0.36	0.003	0.36	5E-07
R ²	0.08		0.11		0.15		0.10	
Sample size	4904		7697		891		2295	

The results for linear regression for different intersections are presented in table 1. The different components in the regression output are explained as follows. Variable denotes the independent variables chosen to predict the discharge headway values. Estimate stands for the value representing the effect of corresponding variable towards the dependent variable. The next section which gives the p value for each parameter tests the null hypothesis that coefficient is equal to zero. Lower p value means the null hypothesis can be rejected which in turn indicates that the corresponding variable is significant in the model.

The analysis is done keeping the effect of two wheelers as the base. Each of the estimate values shows the effect of corresponding variables on discharge headway. More specifically, for the output for location A evening data, the intercept represents the headway of two wheelers in the middle strips (4, 5, 6, and 7) at the start of the green time. The corresponding headways of *car*, *auto*, *lcv* and *hmv* are respectively 0.260, 0.198, 0.908, and 1.834 seconds higher. It can be seen that coefficient of time has a positive value which shows that with increase in green interval time, discharge headway increases. It is evident from the results that vehicle type has significant impact on discharge headway. In all the study areas except location B, all variables representing vehicle type are significant. The estimate of the variable *nearerb* is negative for location A which indicates that discharge headway values of vehicles close to the kerb is lower compared to the discharge headway values of vehicles near median or middle of the road section. This could possibly be a result of aggressive drivers preferring lane closer to kerb or due to the presence of right turning vehicles near median. Positive values for *nearerb* for locations B and C may be because of the side friction (presence of shops or other structures very close to road section) at these locations. Data has been collected from location A during both morning and evening peak periods. The first two sections in the above table shows the results for these two datasets. It can be observed that though the data is from the same location, the estimates for the independent variables calculated from the morning and evening data are found to be different. During morning as most commuters are going to work we expect more aggressive behaviour. But due to over aggressive nature, vehicles impede each others movement by waiting too close to each other and as a result are not able to discharge freely during green signal. This could explain the higher estimate values for morning peak periods compared to peak periods in evening. The results from different locations vary as the factors such as geometric conditions, number of lanes, traffic composition, level of congestion vary at different intersections. Low R² for all the study locations is due to the high variability in the data and possibly due to the omission of other factors on which discharge headway depends. To better capture this variability a linear mixed model is used to represent discharge headway which is explained in the next section.

5.4. Linear Mixed Regression Model

Linear mixed effects models can be treated as an extension to linear regression models for grouped data. Such models describe the relationship between a dependent variable and independent variables with coefficients that can vary with respect to one or more grouping variables. A linear mixed effect model has two parts - fixed effects and random effects. Fixed effect variables comprise those which are repeatable with similar pattern over time and are similar to the independent variable in linear regression models. Random effect variables come from a larger population and thus it is much better to focus on their variances rather than estimating means. Linear regression assumes error terms to be independent and have equal variances. But clustering of observations within group will lead to correlated error terms, biased estimates of parameter and standard errors. By using linear mixed model, it allows different error variance for each of the levels present in random variable. A general matrix form for a linear mixed model is as follows.

$$Y = X\beta + Z\gamma + \epsilon \tag{2}$$

Where Y is the response vector matrix, X is the matrix with fixed effect values, β is the vector of estimates of fixed effects, Z is the matrix with random effect values, γ is the vector of estimates of random effects and ϵ represents the vector containing residual errors. β describes the change in mean response over time for one unit change in the corresponding fixed effect. γ represents the deviation of observations in a group from the population mean intercept. The following form for linear mixed model is assumed and is regressed to obtain the respective coefficients for fixed and random effects.

$$Headway = \beta_0 + \beta_1time + \beta_2median + \beta_3nearerb + \gamma_1vehtype \tag{3}$$

Where *headway* represents discharge headway, *time*, *median* and *nearerb* are fixed effect variables and *vehtype* is the random effect variable. Fixed effect variables used are same as that in linear regression. The variable *vehtype* represents the five different vehicle classes analysed in this study. The above model specification is used for performing linear mixed regression to compute the respective coefficients.

Table 2. Results for Linear mixed regression

	Location A Tidel Evening		Location A Tidel Morning		Location B Thiruvannmiyur		Location C Adyar Depot	
Fixed effects:	Estimate	p value	Estimate	p value	Estimate	p value	Estimate	p value
Intercept	2.43	0.003	2.62	0.005	2.57	0.009	2.42	0.002
time	0.003	5E-11	0.0008	0.0009	0.006	0.0008	0.008	1E-13
median	0.32	6E-09	0.11	0.007				
nearerb	-0.17	0.0006	-0.22	1E-09	0.32	0.006	-0.15	0.05
Random effects:	Std Dev	p value	Std Dev	p value	Std Dev	p value	Std Dev	p value
vehtype	0.87	<2E-16	1.07	<2E-16	1.23	<2E-16	0.79	<2E-16
Residual	1.48		1.37		1.67		1.64	
Marginal R ²	0.02		0.01		0.01		0.02	
Conditional R ²	0.27		0.38		0.36		0.20	

Results for linear mixed regression analysis are presented in table 2. Fixed effects section output is interpreted in the same way as that of linear regression. Intercept represents the average value for discharge headway. Positive coefficient for variable time for all the study areas indicates an increase in discharge headway over green time. Location A has three lane road sections and other two locations have two lane road sections. For location A the effect

of lateral position is captured through the variables *median*, *middle* and *nearerb* out of which *middle* is kept as base. For locations B and C, only the variables *median* and *nearerb* were used since they were two lane road sections and median is kept as base. The next section is that of random effects. Standard deviation represents the amount of variability in the dependent variable explained by the random effects variable. *Residual* denotes the variability that is not accounted by the model. Linear mixed model regression output does not provide R^2 by default. It is also different from what is observed for a linear regression model. Nakagawa and Schielzeth (2013) has provided a method for obtaining R^2 for linear mixed models which is followed in this study also. R^2 value is presented as two parts which includes marginal R^2 and conditional R^2 . Marginal R^2 describes the proportion of variance explained by fixed factors alone whereas conditional R^2 describes the proportion of variance explained by both fixed and random effects.

An interesting observation in the output is that the estimate of variable *nearerb* for location C, which was significant in linear regression output is not significant here. This shows that the linear model discussed earlier was having a bias, due to which the variable *nearerb* was significant and thus making the estimates for other variables inaccurate. By using linear mixed model this bias could be corrected and thus provide correct estimates for the remaining variables. An important feature of linear mixed model is that it will assign different intercept for each of the levels assigned as random effects variable. Table 3 shows estimates for random effects and the corresponding random intercepts. It can be observed that each vehicle type is assigned a different intercept and thus mixed model takes into account the variability due to vehicle type on discharge headway. Random intercept values are obtained by the algebraic sum of estimates and the overall mean value. From the results it could be seen that across different study areas, the intercepts for each of the vehicle type are comparable. Two wheelers are found to have the lowest value and heavy vehicles have the higher value. The intercept values for 2W, 3W, car, LCV and HMV by linear regression for location C are respectively 1.45, 1.75, 1.63, 2.35 and 3.45. But the corresponding values by linear mixed regression for 2W, 3W, car, LCV and HMV are respectively 1.7, 1.99, 1.83, 2.49 and 3.56. There is significant difference among the values which may be due to the bias present in linear model resulting in incorrect estimates. The results show the importance of specifying error terms more accurately through linear mixed models. The discharge headways play a major role in determining saturation flow and capacity. More accurate estimates of discharge headways could improve intersection signal operations.

Table 3. Random effect estimates and random intercepts.

vehtype	Location A Tidel Evening		Location A Tidel Morning		Location B Thiruvanmiyur		Location C Adyar Depot	
	Estimate	Intercept	Estimate	Intercept	Estimate	Intercept	Estimate	Intercept
auto	-0.49	1.94	-0.68	1.93	-0.87	1.70	-0.40	2.02
car	-0.46	1.98	-0.45	2.17	-0.65	1.91	-0.54	1.88
hmv	1.43	3.86	1.77	4.39	1.95	4.51	1.14	3.56
lcv	0.19	2.62	0.19	2.80	0.39	2.96	0.44	2.85
twow	-0.68	1.76	-0.82	1.79	-0.81	1.75	-0.64	1.78

6. Conclusions

This study was carried out to understand discharge headway and the factors affecting it under heterogeneous traffic conditions and develop models to represent discharge headway. Discharge headway values were having variation and were different from homogeneous traffic scenario where the headway tends to follow a constant value after initial four or five vehicles. Vehicle type, lateral position of vehicle in road section, and elapsed green time were identified as the factors affecting discharge headway. Models for computing discharge headway were developed using linear regression and linear mixed regression. Linear model had bias which was eliminated using linear mixed model. Further research could be done on studying the effect of geometric factors such as grade and curvature, and effect of turning movements on discharge headway. Few other factors such as vehicle composition, driver and pedestrian behaviour, and presence of bus stops near intersection could improve the performance of model.

References

- Al-Ghamdi, A., 1999. Entering Headway for Through Movements at Urban Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board* 1678, 42–47.
- Arasan, V., Koshy, R., 2005. Methodology for Modeling Highly Heterogeneous Traffic Flow. *Journal of Transportation Engineering* 131, 544–551.
- Arasan, V.T., Vedagiri, P., 2006. Estimation of Saturation Flow of Heterogeneous Traffic Using Computer Simulation, in: 20th European Conference on Modelling and Simulation, Bonn, Germany.
- Bonneson, J.A., 1992. Study of Headway and Lost Time at Single-Point Urban Interchanges. *Transportation Research Record* , 30–39.
- Carstens, R.L., 1971. Some Traffic Parameters at Signalized Intersections. *Traffic Engineering* 41, 371–375.
- Greenshields, B.D., Schapiro, D., Ericksen, E.L., 1947. Traffic Performance at Urban Street Intersections. *Eno Foundation for Highway Traffic Control* , 23–30.
- Jin, X., Zhang, Y., Wang, F., Li, L., Yao, D., 2009. Departure Headways at Signalized Intersections: A Log-Normal Distribution Model Approach. *Transportation research part C: emerging technologies* 17, 318–327.
- Liu, M.J., Mao, B.H., Chen, S.K., Gao, L.P., Sun, Q.X., 2011. An Exploratory Hazard-based Analysis of the First Discharge Headway. *Procedia - Social and Behavioral Sciences* 16, 536–547.
- Maini, P., Khan, S., 2000. Discharge Characteristics of Heterogeneous Traffic at Signalized Intersections. *Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity, 2000* , 258–270.
- Moussavi, M., Tarawneh, M., 1990. Variability of Departure Headways at Signalized Intersections. *ITE 1990 Compendium of Technical Papers* , 313–317.
- Nakagawa, S., Schielzeth, H., 2013. A General and Simple Method for Obtaining R^2 from Generalized Mixed-Effects Models. *Methods in Ecology and Evolution* 4, 133–142.
- Radhakrishnan, P., Mathew, T.V., 2011. Passenger Car Units and Saturation Flow Models for Highly Heterogeneous Traffic at Urban Signalised Intersections. *Transportmetrica* 7, 141–162.
- Ramadurai, G., 2013. Manual Counting Made Easy (MCME) Software, Available Online at: <http://coeut.iitm.ac.in/software.html>.
- Remias, S.M., Hainen, A.M., Day, C.M., Brennan Jr, T.M., Li, H., Rivera-Hernandez, E., Sturdevant, J.R., Young, S.E., Bullock, D.M., 2013. Performance Characterization of Arterial Traffic Flow with Probe Vehicle Data. *Transportation Research Record: Journal of the Transportation Research Board* .
- Rossi, R., Gastaldi, M., 2012. An Empirical Analysis of Vehicle Time Headways on Rural Two-lane Two-way Roads. *Procedia - Social and Behavioral Sciences* 54, 865–874.
- Wu, J., Hu, J., Sun, J., 2010. Departure Headway Distribution Modeling for Ordinary Large Cities Based On Video Information. *Computer Sciences and Convergence Information Technology (ICCIT), 2010 5th International Conference on. IEEE* , 1040–1045.
- Yin, S., Li, Z., Zhang, Y., Yao, D., Su, Y., Li, L., 2009. Headway Distribution Modeling with Regard to Traffic Status. *2009 IEEE Intelligent Vehicles Symposium* , 1057–1062.