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Car Following Analysis using GPS Data

Gopika Unni[1], Ashalatha R[2]

[1]*Assistant Professor, Ahalia Health,Heritage & Knowledge Village, Kozhippara, Palakkad,Kerala,India.Pincode - 678 557.*
[2] *Professor and Head of the Department of Civil Engineering , Govt. College of Engineering Kannur, Mangattuparmba, Parassinikkadavu P.O. Kannur 670563 Kerala.*

Abstract - *A major element in the evolution of traffic flow has been the development of the car following theory. Car following theory is an important element of traffic modeling. It describes a theoretical interaction of two or more cars while driving which is an essential input for transport network models as it directly implies the time and space they will take up during driving. This in turn will affect the theoretical capacity of roads in such models. The study on car following dynamics is useful for capacity analysis, safety research and traffic simulation. In this work, the car following behavior for distinct lead-following vehicle type combinations is studied. Data was collected using vehicles equipped with GPS receivers under heterogeneous traffic conditions. Four vehicle type combinations were selected by considering car and auto rickshaw as lead and following vehicles. Test vehicles were driven along two specified stretches (one divided stretch and one undivided stretch) in Trivandrum city. The latitude and longitude coordinate information as well as speed and time data for test vehicles were obtained. These data were used to calculate the space headway between the vehicles. Using this data various analyses were done and the conclusions were drawn. The conclusions from this project include the determination of relationship followed by spacing and speed of vehicles and the variation of this relationship for different combination of lead and following vehicles. Additionally this project allowed identifying whether the hysteresis effect exists in urban conditions of developing countries and to quantify the obtained hysteresis.*

Key Words: Car –following, GPS, Heterogeneous traffic Hysteresis

1. INTRODUCTION

Car following behaviour describes the way one vehicle follows another in a single lane of traffic. The basic concept of car following theory is that the actions of a vehicle on the road are governed by the actions of the vehicle immediately preceding it[7] (Wolshon et al. 2000).
Car following theories were developed mainly in the 1950s and 1960s. One of the most important study in the field of car following was undertaken by the researchers at the General Motors Corp. (GM). A number of car following models were formulated by the GM researchers. Since then various researches were undertaken and different car following models were developed.

The models developed are for homogeneous traffic conditions and for similar leader and follower vehicle-types. However, the type of vehicle can have a significant influence on the following behaviour especially in heterogeneous traffic. Therefore in order to model the car following behaviour under heterogeneous traffic, proper understanding of the car- following process in heterogeneous traffic conditions is required. Attempts have been made by many researchers to modify the existing car following models by incorporating vehicle type specific parameters into them. The present study analyses car following behaviour in heterogeneous traffic conditions on two different types of facilities namely, divided and undivided roads in India.

2. OBJECTIVES

This study aims at understanding the car-following behaviour of various vehicle type combinations in heterogeneous traffic conditions. The main objectives of this study are:

I. To determine whether a distinct car- following behaviour exists for different combinations of lead- following vehicles under heterogeneous traffic conditions.

II. To determine the variation of space headway under different combinations of lead- following vehicle types.

III. To determine whether hysteresis exists under heterogeneous traffic and if so, to quantify it.

3. REVIEW OF LITERATURE

Wolshon et al. (2000) conducted a car following study in which Global Positioning System (GPS) was used to collect car following data according to the procedures developed by researchers at Louisiana State University. With the data collected the numeric values of driver sensitivity and time lag were calculated using the General Motors car following models. These values were then compared to the original GM values. The results of this study were found to be consistent with those of GM research.

Shekleton (2002) conducted a car following study at the University of New South Wales (UNSW) compound, the objective of which was to address the lack of accurate car following data by using differential GPS for data collection. Car spacing relationships including hysteresis effects and vehicular acceleration characteristics were analysed. This study provided ample and accurate car following data that established GPS as an appropriate tool for data collection in urban areas. This study also provided a number of valuable conclusions about car following, like existence of a linear minimum spacing – speed relationship, existence of a pattern indicating a relationship between acceleration and speed characteristics of drivers and that several elements of car following in practice depend on individual or stochastic effects.

Tom and Ravishankar (2010) conducted a study in which they presented reviews of the different car-following models. The car following behaviour for distinct lead-following vehicle type combinations were also studied in order to find the effect of vehicle type on following behaviour. Data was collected using vehicles equipped with GPS receivers under heterogeneous traffic conditions. Six vehicle type combinations were selected by considering car, auto rickshaw and bus as lead and following vehicles. From the collected data the desired spacing was calculated, which was found to be different for each vehicle type combination, indicating the existence of distinct car following behavior for different vehicle combinations. The results suggested that following behavior depended on the type of lead and following vehicle. Hence they suggested incorporation of vehicle type specific parameters in car following models for heterogeneous traffic conditions.

Ahn (2010) conducted a study in which traffic hysteresis was analysed by studying the speed-spacing relationship as a vehicle undergoes deceleration followed by acceleration due to a stop-and-go disturbance. Instead of observed spacing, estimated spacing in equilibrium was used to account for continuous accelerations and decelerations. Findings showed that reverse hysteresis cases (counter-clockwise evolution of speed-spacing relations) were often observed, especially on the fast (left-most) lane. The study also presented a method to quantify hysteresis. Hysteresis was measured as the average difference in spacing during acceleration and deceleration and this magnitude was found to be about a vehicle length (≈ 20ft) or less and increased toward outer lanes.

Tom and Ravishankar (2011) in their study modified the Gipps' car-following model by incorporating vehicle-type dependent parameters. The modified model was studied at microscopic as well as macroscopic level using data collected from both homogeneous and heterogeneous traffic conditions using different combinations of lead-follower vehicle types. The results obtained for the modified and original Gipps' model were compared with the field values and it was found that the modified model performed better. Thus the results indicate that the modifications proposed in the Gipps' model enhanced the prediction of following behaviour and suggested the need of incorporating vehicle type specific parameters into traffic simulation models.

Tom and Ravishankar (2012) further conducted a study in which a neural network model was proposed to predict the car-following behaviour for different lead and following vehicle-type combinations. Data for the study was collected for six vehicle-type combinations using vehicles equipped with GPS receivers. A multi-layer feed-forward back propagation network was used to predict vehicle-type dependent following behaviour by incorporating the vehicle-type as input into the model. The neural network model was then integrated into a simulation program to study the macroscopic behaviour of the model. Performance of the neural network model was compared with the conventional Gipps' model at microscopic and macroscopic level. The results revealed that the neural network model performed better than the conventional Gipps' model thus suggesting that in mixed traffic conditions neural networks were highly suitable in modelling car following behaviour.

4. METHODOLOGY

The methodology includes data collection, extraction of the collected data and analysis of the data in order to analyse the car following behaviour in heterogeneous traffic conditions.

4.1 Data Collection

The most basic data required for studying car following behaviour is speeds of the leader and the follower vehicles and the space headway between the vehicles. In the present study this data was collected using Garmin eTrex Vista HCx Hand-held GPS. This GPS receiver fitted in the moving vehicles recorded instantaneous position (latitude and longitude) and speed at periodic intervals of one second. For this study, data was collected from two stretches in Thiruvananthapuram city:

1. LMS Junction to East Fort (4 lane divided)
2. Over bridge to Thampanoor (4 lane undivided)

The details of the study sections are shown in Table 1.

Table -1: Details of study sections

Section	Name of	Type	Presence
1	LMS Junction-	Divided	Yes
2	Over bridge-	Undivided	No

Experiments were conducted using four combinations of vehicles comprising of passenger car and three wheeled auto-rickshaw. The four combinations were namely, three wheeled auto-rickshaw following another three wheeled auto-rickshaw (A-A), passenger car following another passenger car (C-C), three wheeled auto-rickshaw following a passenger car (C-A) and passenger car following a three wheeled auto-rickshaw (A-C). Data was collected during peak time of the day and three runs were conducted for each vehicle combination. Driver of the lead vehicle was asked to

follow the traffic stream and the following vehicle driver to follow the lead vehicle without overtaking. It was ensured that the drivers selected for the study were not aware of the objectives of the study. They were in the age group of 25 to 30 years. Data sets containing extrusion of other vehicles between lead and following vehicles were excluded.
GPS data was extracted using Map Source software. Velocity and position at second by second intervals were obtained. The data was then imported to Microsoft Excel and the position and speed data of the leader vehicle were matched with the corresponding follower data and merged into a single data set. Duration of data collection for each combination of vehicle type considered for analysis is given in Table 2.

Table -2: Duration of data collection for each combination of vehicle types

Lead vehicle	Following vehicle	Total duration (seconds)	
		Section 1	Section 2
A	A	837	192
C	C	645	359
C	A	500	208
A	C	541	177

4.2 Computation of Space Headway

The GPS data obtained from the leader and follower vehicles were synchronised to get the information of the leader and follower at every instant. For any given instant the space headway between the two vehicles i.e. the distance from the front of the lead vehicle to the front of the follower vehicle, is calculated from the position (latitude and longitude) of the leader and follower using the equation 1:

Space headway, $d= \sqrt{(X2+Y2)}$ (1)

where, $X=\Delta$ Longitude × cos(Latitude)

here, Latitude= (Latitude lead+ Latitude follower)/2

$Y= \Delta$ Latitude and R= radius of Earth (6371km)

Acceleration of a vehicle is calculated by differentiation of speeds. A sample of the fully compiled data obtained after the computation of space headway is shown in Table 3

Table -3: Sample data for lead vehicle (Passenger Car) and following vehicle (Passenger Car) for divided section

Time (hr:min:sec)	Leader			Follower			Space headway (m)
	Speed (km/h)	Lat	Long	Speed (km/h)	Lat	Long	
1:57:46	0.4	N8 30 23.9	E76 57	0.5	N8 30	E76 57	36.578
1:57:47	0.7	N8 30 23.9	E76 57	0.5	N8 30	E76 57	36.578
1:57:48	7	N8 30 23.9	E76 57	0.2	N8 30	E76 57	36.578
1:57:49	5	N8 30 23.9	E76 57	0.2	N8 30	E76 57	35.368
1:57:50	3	N8 30 23.9	E76 57	2	N8 30	E76 57	34.799

5. DATA ANALYSIS AND RESULTS

Speed and space headways are obtained for all the different combinations of lead-following vehicle pairs for the divided and undivided sections. These values are then used for further analysis.

5.1 Velocity- Time Relationships

The speed profiles of lead vehicle (LV) and following vehicle (FV) for different combinations of vehicles were plotted and are given in charts 1-4.

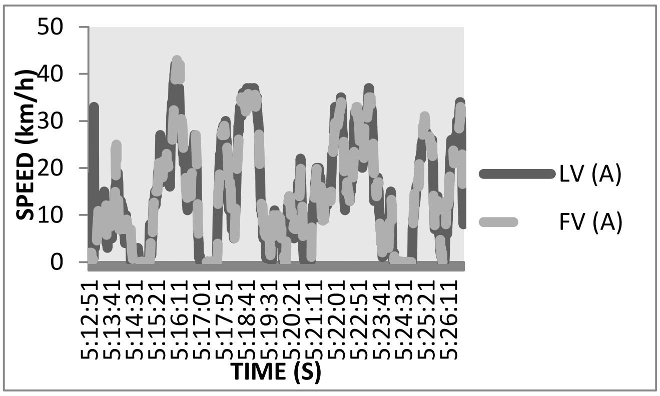

Chart1a- Speed -Time profile for Auto rickshaw following another Auto rickshaw in divided section

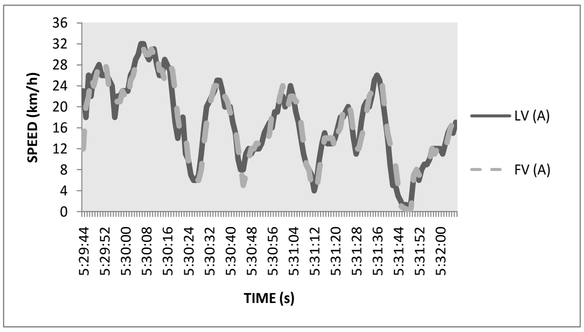

Chart1b -Speed - Time profiles for Auto rickshaw following another Auto rickshaw in undivided section

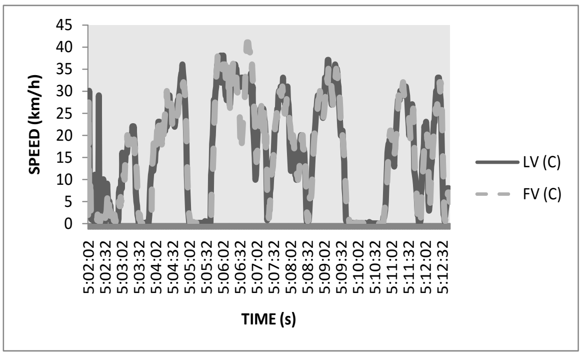

Chart 2a -Speed - Time profiles for Car following another Car in divided section

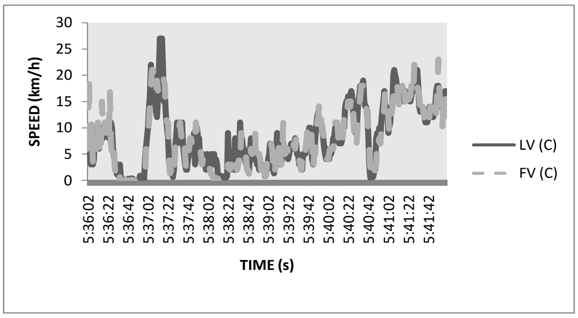

Chart 2b- Speed - Time profiles for Car following another Car in undivided section

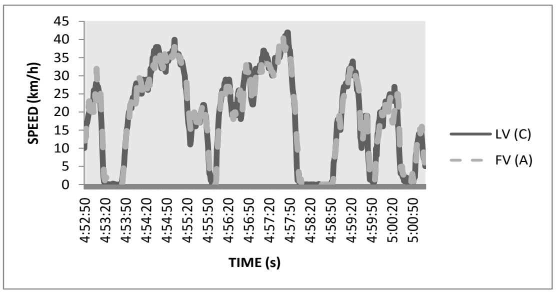

Chart 3a Speed -Time profiles for Auto rickshaw following Car in divided section

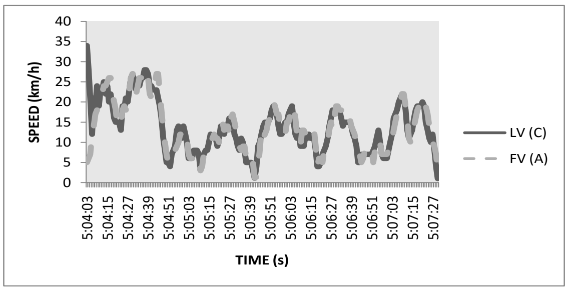

Chart 3b -Speed - Time profiles for Auto rickshaw following Car in undivided section

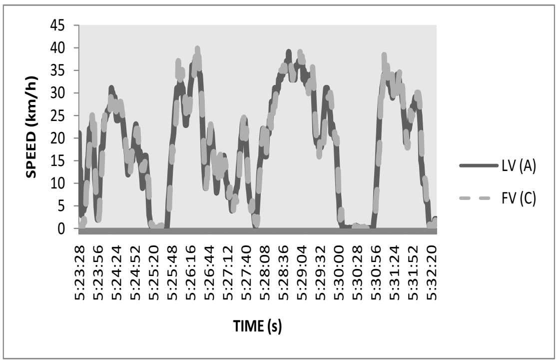

Chart4a -Speed - Time profiles for Car following Auto rickshaw in divided section

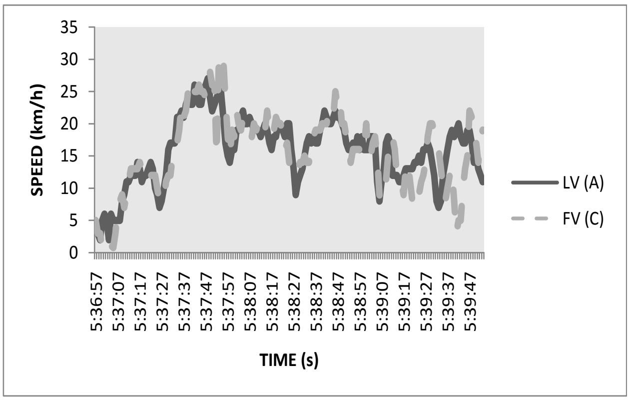

Chart 4b- Speed - Time profiles for Car following Auto rickshaw in undivided section

Charts 1-4 clearly indicate that the speed of the following vehicle is significantly affected by the speed of the lead vehicle suggesting the existence of car-following behaviour in heterogeneous traffic conditions also. The mean speeds of the leader and following vehicle at section 1 and section 2 for different combinations of leader and follower vehicle types are shown in Tables 4 and 5. These mean speeds indicate a strong correlation between the speeds of leader and follower vehicle types indicating the existence of car following behaviour.

Table -4: Comparison of mean speed at divided section

Vehicle combinations	Mean speed km/h	
	Lead vehicle	Following vehicle
A-A	14.3	14.1
C-C	15.6	15.44
C-A	18.69	18.746
A-C	17.8	17.7

Table- 5: Comparison of mean speed at undivided section

Vehicle combinations	Mean speed km/h	
	Lead vehicle	Following vehicle
A-A	16.9	16.9
C-C	8.1	7.9
C-A	13.66	13.33
A-C	15.8	15.5

5.2 Relative Speed- Space Headway Relationships

The most effective way of analysing car following behaviour is through plots of spacing versus. speed. The space headway and the relative speed from the four different vehicle combinations are extracted from the data. Relative speed is calculated as the difference between the speed of the lead and following vehicles. The plots between space headway and relative speed for the different vehicle combinations obtained from the study are shown in charts 5-8.

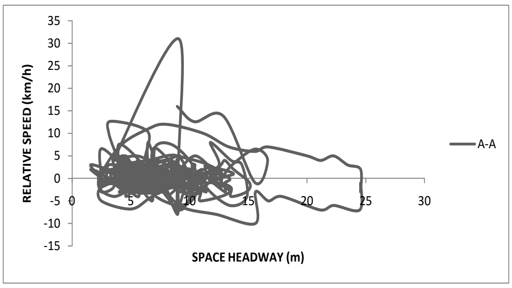

Chart 5a -Relative speed Vs. Space headway profile for Auto rickshaw following another Auto rickshaw in divided section

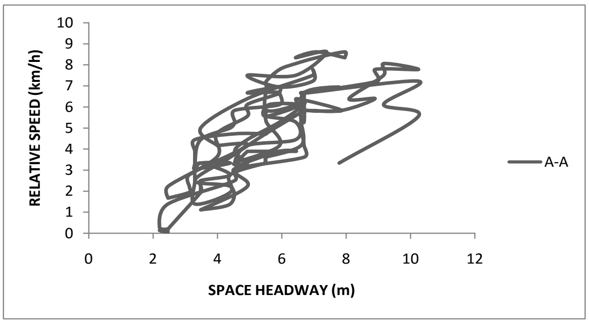

Chart 5b- Relative speed Vs. Space headway profile for Auto rickshaw following another Auto rickshaw in undivided section

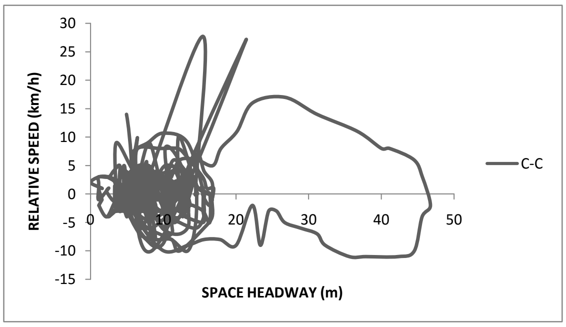

Chart 6a- Relative speed Vs. Space headway profile for Car following another Car in divided section

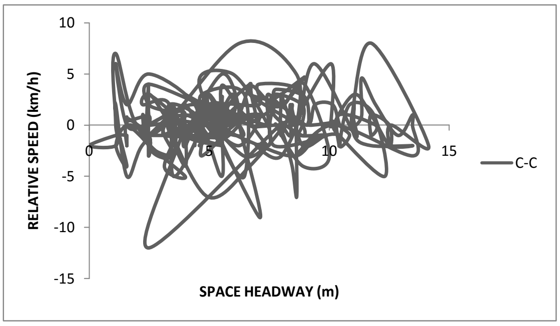

Chart.6b -Relative speed Vs. Space headway profile for Car following another Car in undivided section

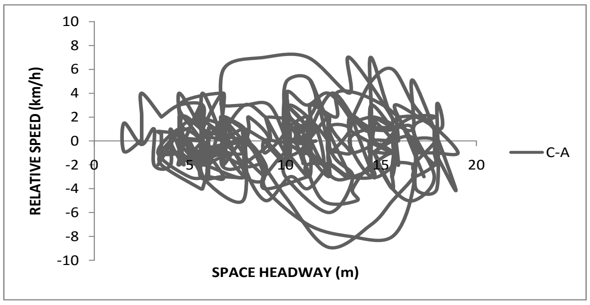

Chart 7a- Relative speed Vs. Space headway profile for Auto rickshaw following Car in divided section

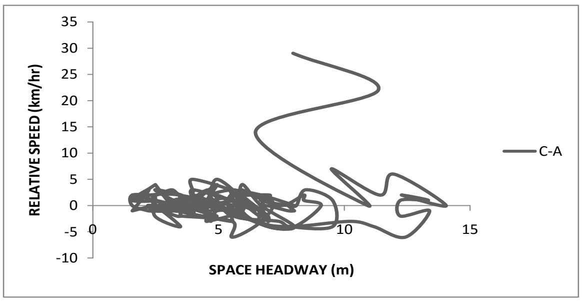

Chart.7b- Relative speed Vs. Space headway profile for Auto rickshaw following Car in undivided section

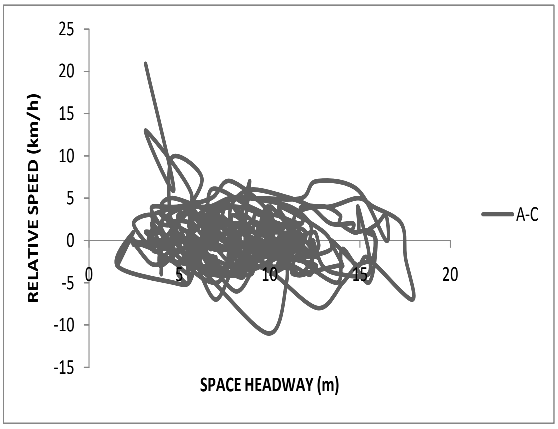

Chart.8a -Relative speed Vs. Space headway profile for Car following Auto rickshaw in divided section

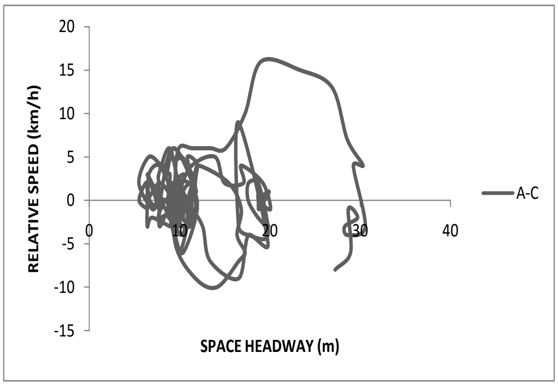

Chart.8b- Relative speed Vs. Space headway profile for Car following Auto rickshaw in undivided section

5.3 Analysis of Space Headway

From the relative speed Vs. space headway plots it can be seen that in each plot the space headway tends to concentrate or spiral towards a point which can be interpreted as the desired space headway ([5]Tom and Ravishankar, 2010).

This supports the previous observation by Tom and Ravishankar in their car following study conducted using data collected from Eastern and Western express highways in Mumbai, India in the year 2010. The Figures 5-8 imply that the separation at which a vehicle pair stabilizes is not actually a constant but oscillates (drifts) around a desired distance ([5]Tom and Ravishankar, 2010).

The mean space headways of various vehicle type combinations for the sections 1 and 2 are shown in Table 6.

Table- 6: Comparison of mean space headway of divided and undivided sections

Vehicle combinations	Mean space headway	
	Divided Section (m)	Undivided Section (m)
A-A	7.25	5.4
C-C	8.8	5.97
C-A	9.72	5.2
A-C	8.11	12.34

From Table 6, it is seen that the space headway is different for different vehicle combinations.

The Table 6 also indicates that space headway is higher in divided section compared to the undivided section. This would be due to more disciplined traffic in the divided section. As a result of this disciplined movement the drivers are able to maintain a desired or safe gap. From the Table 6 it can also be seen that space headway is less for auto following car combination. The reason for this might be due to the aggressive behavior of drivers.

5.4 Hysteresis Analysis

Traffic hysteresis is characterized by the retardation in the recovery of speed as vehicles emerge from a kinematic disturbance, resulting in a greater spacing during acceleration for a given speed as compared to deceleration [1](Ahn, 2010). This characteristic of individual spacing preferences and reaction times appears in the form of looping strings of data points on speed versus spacing plots. The loops represent the reaction of a following car to some form of speed disturbance[4] (Shekleton, 2002).

Previous studies have defined the hysteresis effect as sequences where a follow drivers spacing during periods of acceleration is significantly larger than their spacing during a preceding or following period of deceleration. This characteristic is attributed to an individual lag in driver reaction time [4](Shekleton, 2002).

In order to examine the existence of hysteresis in heterogeneous traffic conditions and to quantify hysteresis, for each pair of vehicles, the space headway-speed relationship of the following vehicles is examined during a cycle of deceleration followed by acceleration.

If traffic hysteresis is present, the acceleration branch should exhibit a larger spacing than the deceleration branch for a given speed; i.e., the spacing vs. speed should display a clockwise loop. These relationships which are in the form of hysteresis loops are illustrated in Figures 9-12.

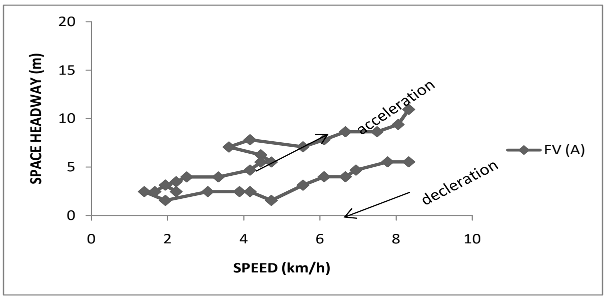

Chart -9a: Hysteresis loops for Auto rickshaw following another Auto rickshaw in divided section

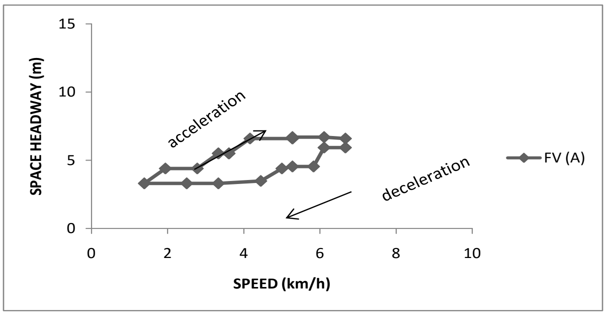

Chart.9b Hysteresis loop for Auto rickshaw following another Auto rickshaw in undivided section

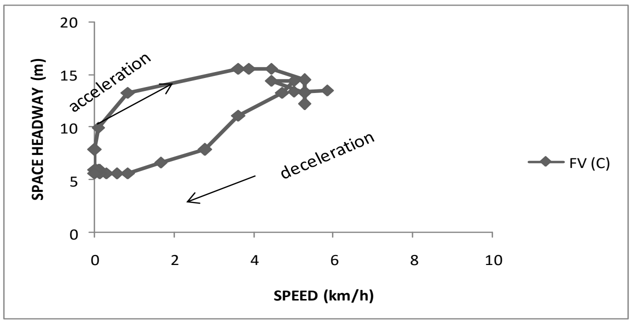

Chart 10a Hysteresis loop for Car following another Car in divided section

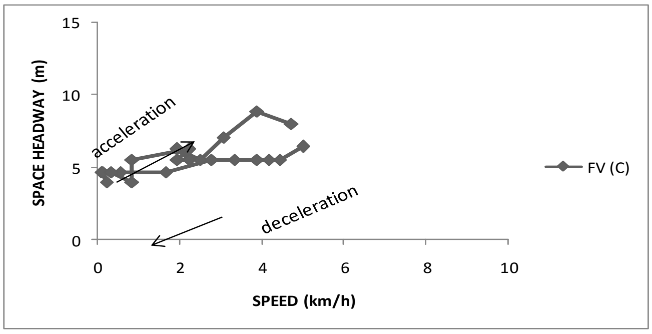

Chart-10b : Hysteresis loop for Car following another Car in undivided section

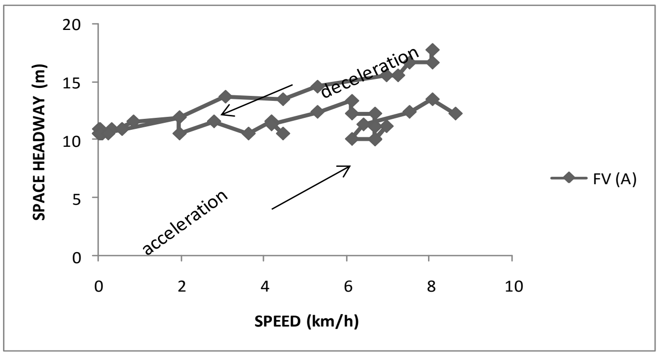

Chart 11a Hysteresis loop for Auto rickshaw following Car in divided section

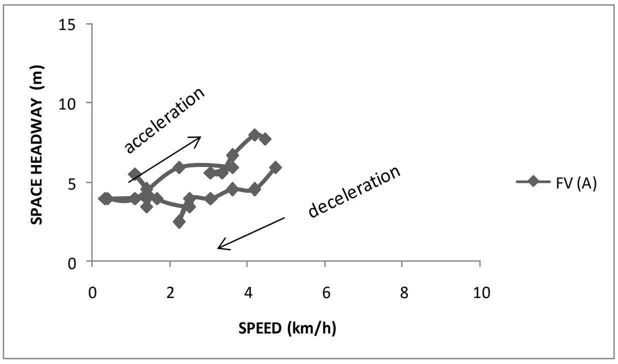

Chart.11b Hysteresis loop for Auto rickshaw following Car in undivided section

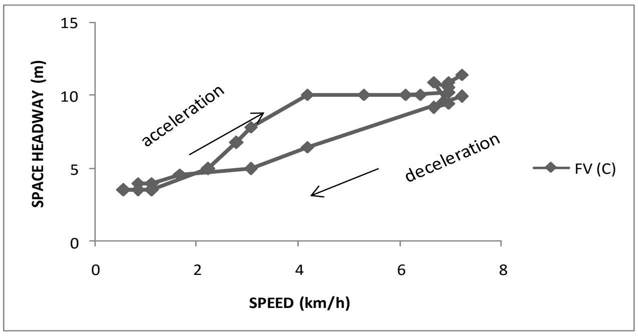

Chart-12a :Hysteresis loop for Car following Auto rickshaw in divided section

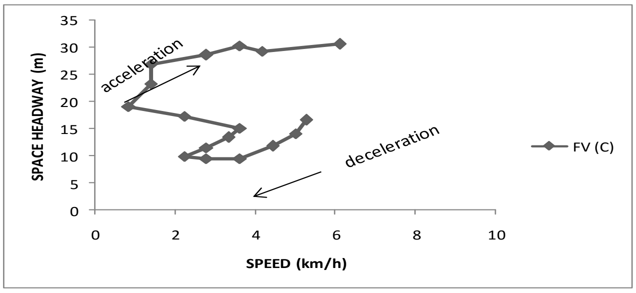

Chart12b Hysteresis loop for Car following Auto rickshaw in undivided section

5.5 Quantification of Hysteresis

Hysteresis is quantified as the average difference in spacing over the span of a loop. For this the area of each loop is obtained by summing the area of individual trapezoids bounded by neighbouring speed measurements, as illustrated in Chart13. Then for each case, the average difference in spacing, ∆s is computed as the area divided by the speed span, ∆v [1](Ahn, 2010).

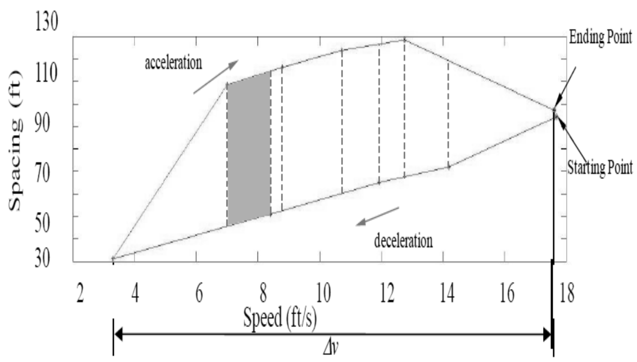

Chart 13 Measurement of Hysteresis by Calculating Area of the Loop Source : Ahn, (2010)

Using this method hysteresis is quantified for all the different combinations and is tabulated as given in Table 7.

Table- 7 :Hysteresis values for different vehicle combinations

Vehicle combinations	Divided Section (m)	Un Divided Section (m)
A-A	2.35	2.49
C-C	4.9	3.23
C-A	2.5	2.1
A-C	3.78	3.3

From the hysteresis values obtained it can be seen that the difference in spacing is different for different vehicle combinations. This spacing is almost a vehicle length and it is found to be lesser for vehicle combinations involving autorickshaw. The hysteresis value is seen to be higher in divided lanes. This may be due to the higher space headway in divided sections.

6. CONCLUSIONS

The study on car following dynamics is useful for capacity analysis, safety research and traffic simulation. An understanding of the car-following behaviour in heterogeneous traffic conditions is needed to model the exact vehicular behavior simulating studies for better results. This study investigates car-following behavior in urban 4 lane divided and undivided roads with mixed traffic in a developing country, India. The conclusions that can be drawn from the study are:

- Velocity-time graphs indicated that car following behaviour existed in mixed traffic conditions.
- Space headway was also found to be different for different vehicle combinations. It was found to be maximum for autorickshaw following car combination in the divided section and car following autorickshaw in the undivided section. Space headway was minimum for autorickshaw following autorickshaw in the divided section and autorickshaw following car combination in the undivided section.
- Space headway was seen to be higher in divided section since traffic was more disciplined and as a result the drivers were able to maintain a safe gap.
- Space headway was found to be less for auto following car combination. This was because this auto rickshaw was driven very aggressively which was an observation specifically noted during data collection.
- When speed -spacing relationships were plotted they formed looping strings. This observation made it evident that hysteresis effect did exist in heterogeneous traffic conditions.
- Hysteresis was quantified and it was found to be different for different vehicle combinations and higher in divided lane compared to undivided lane. The highest values of hysteresis were found for car following car combination for both the divided (4.9 m) and undivided (3.23m) sections. This may be due to the higher space headway for the car following car combination.

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