European Transport \ Trasporti Europei n. 45 (2010): 50-63

Cellular automata cell structure for modeling heterogeneous traffic

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Abstract

Gap maintaining behavior significantly affects the traffic flow modeling under heterogeneous traffic conditions. The clearance between two adjacent moving vehicles varies depending on several traffic conditions. From the data collected on the gap maintaining behavior it has been observed that vehicles maintain different gaps when travelling under different traffic conditions and this is also influenced by lateral position of the vehicle. Mallikarjuna (2007) has found that this variable gap maintaining behavior can be explained using a macroscopic traffic characteristic called area occupancy. In this study, these relationships would be used in deciding the cell width which is the basic input for cellular automata (CA) based heterogeneous traffic flow models. It is proposed that the dominant vehicle in the traffic stream, its lateral position, and lateral gaps on either side are the governing factors in deciding the cell width. Cell width has been finalized based on this input and it is found to be varying when area occupancy is varying from 3 to 15%.

Keywords: Heterogeneous Traffic; Cellular Automata; Varying cell width; Area occupancy.

1. Introduction

Traffic flow models are crucial in implementing transportation planning and traffic management measures. Several types of traffic models such as models based on kinematic wave theory, Gas kinetic theory, and car following theory are available for this purpose. Wide ranging physical dimensions, weight, dynamic characteristics of vehicles makes it difficult to apply these models for heterogeneous traffic. A driver, traveling under these conditions, can utilize any space available on the road without any lane discipline. Many researchers have worked on it and developed some suitable solutions to model the heterogeneous traffic but their applicability is limited due to difficulties in data collection. When different types of vehicles share the same road space without any physical segregation, the extent of vehicular interactions varies

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widely with variation in traffic mix and traffic conditions. It also generates significant level of friction to the movement of vehicles in the traffic stream. Solutions to these kinds of traffic problems can be found through systematic study of all the relevant characteristics of traffic, with enough data support. Limited data has been collected to study the inter-vehicular friction (lateral gap) between different types of vehicles moving under various traffic conditions. With this limited data it is really not possible to come to any conclusions. There should be some minimum data available for understanding the gap maintaining behavior. From limited observations, Mallikarjuna (2007) has shown the variation of average gap maintained by vehicles with respect to area occupancy. In this study some more data has been collected and the gap-area occupancy relationships proposed by Mallikarjuna (2007) have been extended. These extended relationships have been utilized in arriving at the cell structure of the Cellular Automata (CA) model for heterogeneous traffic.

In most of the existing CA based models that are dealing with the heterogeneous traffic, certain cell sizes are used to incorporate the behavior of various vehicle types. This cell size is a function of physical dimensions and the lateral gaps maintained by the vehicles. Lateral gaps maintained by vehicles vary depending on the traffic conditions and this variability is not incorporated in any of the CA based models. In heterogeneous traffic conditions, where the lane discipline is absent, the variability in the vehicle and road size, in terms of cells, has significant impact on the model outcome. One example is, under jamming conditions, gaps maintained by vehicles are low and a two-lane road is utilized by vehicles as if the road is 3-lane one. When the vehicles and road geometry are represented using a constant cell size, the model can not represent the above said behavior. This paper explains the influence of the variability in the gap maintaining behavior on the vehicle size and the road geometry expressed in terms of cells.

2. Literature Review

Many models have been developed to model the vehicular behavior on the mid-block sections of urban roads. The review of such research work carried out especially on heterogeneous traffic flow models is presented below. This review is more about the microscopic data used in different traffic flow models. Some of the works done using cellular automata concept are also reviewed.

Nagaraj et al. (1990) investigated the linear and lateral placement of the vehicles in mixed traffic environment to develop a simulation model. They have done extensive data collection studies on gap maintaining behavior of vehicles. Data was collected on a two lane undivided road catering to the bidirectional traffic. Data on lateral and longitudinal gap maintaining behavior was collected in this study. Transverse clearance thresholds for different categories of vehicles from their study are shown in Table 1.

Singh (1999) based on the data collected on gap maintaining behavior, developed a relation between the lateral gap and speed of the interacting vehicles. The minimum and maximum lateral spacing has been estimated for two lane road for different combinations of vehicles. He has also measured the data on lateral gaps from the physical barriers like kerb, median etc. Gundaliya (2005) has developed three CA based models for heterogeneous traffic flow simulation. In case of single lane and two lane heterogeneous traffic flow models, a constant cell width of 5.0 meter was used irrespective of traffic conditions. In this grid based heterogeneous traffic flow model, the cell size has been optimized as 0.9 m X 1.9 m using genetic algorithm. Constant cell width was considered irrespective of traffic conditions. Mallikarjuna (2009) has developed a CA based heterogeneous traffic flow model to study the traffic on midblock road sections. Several microscopic data such as lateral and longitudinal gaps are extracted using a image processing based software called TRAZER. Gap maintaining behavior was explained using area occupancy and it was found that with increasing area occupancy lateral gaps maintained by vehicles are reducing. But this variability in the gap maintaining behavior was not incorporated in the proposed traffic flow model. The cell width was constant irrespective of occupancy, which is a limitation of this model.

Table 1: Transverse clearance thresholds for different categories of vehicles.

Type of Vehicle	*Minimum clearance at zero speed (m)*	*Maximum clearance at 60 kmph speed (m)*
Bus	0.4	1.0
Truck	0.4	1.0
Light commercial vehicle	0.3	0.7
Car	0.3	0.7
Auto-rickshaw	0.2	0.7
Motorized two-wheelers	0.1	0.7
Bicycle	0.1	0.5[a]

Note: [a]Maximum clearance at 20kph.

Gunay (2007) found that more frictional clearances are required with the increasing speed of passing vehicles. Again it was also found that increase in the centre line separation reduces the time headway between the leader and the follower. It was assumed that the speed of a vehicle is affected by the effective route width (ERW). Dey et al. (2008) developed a simulation model for modelling mixed traffic flow on two-lane roads. They found that any vehicle was able to pass the lead vehicle when the lateral clearance was 1.5 times the width of the passing vehicle. But nothing was mentioned about the variation in the lateral clearance requirement with respect to road and traffic conditions.

Lan and Hsu (2006) has introduced the concept of "Common Units" (CUs), in which vehicles and road are represented by cells. They proposed the CU size to be 1.25x1.25 meters. This cell size has been arrived at based on the field data collected on the safe gap requirements for the movement of motor cycles. But there is no clear description of the procedure adopted in arriving at this cell size. Hsu et al. (2007) in another study proposed the CU size to be 1.25x1.0 meters, which is corresponding to a maximum speed equals to 31sites/sec (111.6 kph). They used this grid size for standard freeway lane (3 CUs in lateral direction) and as well as for narrow urban street (2 CUs in lateral direction). The size of the vehicles in terms of cells was decided based on their physical dimensions and the required safe gaps. They used compact cars and a twin-truck for this study but they have not considered motorcycle, bus, and single-unit truck, which are very important to represent the heterogeneous traffic scenario. Lan et al. (2009) proposed a new revised CA model with piecewise-linear speed variation as well as limited deceleration capability using the similar cell sizes proposed in Hsu et al. (2007).

From the literature review it can be observed that a comprehensive approach is lacking when modeling the heterogeneous traffic. Complexity in microscopic data collection, specifically when collecting gap related data, has been one of the major problems faced by the researchers working in this area. Microscopic data on gap maintaining behavior is crucial in developing the microscopic traffic flow models. The objective of this study is to analyze the variable gap maintaining behavior under heterogeneous traffic conditions and to incorporate this behavior in traffic flow models. The influence of the variable gap maintaining behavior on the cell structure of the CA based models is analyzed. Cell width is found to be varying with the traffic conditions which are characterized by area occupancy.

3. Cellular Automata Model

In the CA models of traffic, the position, speed, acceleration as well as time are treated as discrete variables. In CA approach, a lane is represented by one-dimensional lattice and each unit of the lattice represents a cell, which can be either empty or occupied by at least one vehicle or part of the vehicle at a given instant of time. The state of a cell at time t is a function of the states of a finite number of cells (called its neighborhood) at time $t - 1$. These neighbors are a selection of cells relative to the specified cell, and do not change (though the cell itself may be in its neighborhood, it is not usually considered a neighbor). Every cell has the same rule for updating, based on the values in this neighborhood. Each time the rules are applied to the whole grid a new generation is created. Mallikarjuna (2009) has described the details of cell state updating procedure used in the CA model for heterogeneous traffic conditions. Applicability aspects of CA model for heterogeneous traffic is discussed below.

3.1. Applicability of the CA Model for Heterogeneous Traffic

CA model used for homogeneous traffic required modifications in cell structure as well as in updating procedures in both lateral and longitudinal directions. To model no lane-discipline which can be attributed to driver discomfort as well as due to the presence of small sized vehicles, the present concept of lanes may not be useful. It is also planned to include lateral gaps at different traffic conditions in addition to actual vehicle width while deciding the CA structure. The factors mentioned in the remainder of this paragraph differentiate the CA structure for homogeneous and heterogeneous traffic. The cell width must be decided in such a way that the small vehicles such as motorized two wheelers and three wheelers are represented properly. The cell must incorporate the gap maintaining behaviour of different vehicles under different traffic conditions. Gap maintaining behaviour varies depending on flow, occupancy, neighboring vehicle type, and the cell widths are to be changed accordingly. Heterogeneous traffic consists of several types of vehicles, differing in both physical and mechanical characteristics. Hence it is required to group the vehicles either based on physical characteristics or mechanical characteristics. Updating procedure in both lateral and longitudinal directions must be changed in accordance with the cell structure. From this discussion it can be said that the cell structure is crucial in developing the CA based heterogeneous traffic flow model.

4. Data Collection

Data used in this study was collected from two urban mid-block sections of Delhi metro region. First data set was collected on a mid-block section of the Dabri road near Delhi-Noida-Delhi (DND) flyway, connecting Delhi and Noida. This section is a three lane road, with a lane width of 3.4 meters. But the lane markings were not followed by vehicles and effective road width used by vehicles was limited to 8 meters. This road was considered for data collection mainly because of the availability of vantage point to collect the video film. The second data set has been collected on inner ring road, which is one of the major arterials in Delhi near Maharanibag. This road is having a shoulder of 2 meter width and the road width is 10.5 meter. The essential microscopic data related to gap maintaining behavior has been extracted from the trajectory data extracted from the TRAZER. Various data related to microscopic characteristics such as lateral gaps, difference in lateral positions of various groups of vehicles were derived using the trajectory data. Data on microscopic characteristics specifically that are used in finding the cell width are presented here.

4.1. Microscopic Data

Lateral gaps and lateral distribution of vehicles are the important microscopic characteristics about which the data is presented here. When road width is more, there will be more number of vehicles travelling side by side. In this situation finding the cell width is complex and it may take several values. To avoid this scenario major vehicle type in the traffic stream and the lateral distribution of such vehicles under varying traffic conditions are taken as the governing criteria. When more subject vehicles are travelling near median, the effective width of the vehicle is considered as the summation of vehicle width, gap maintained with median and half of the gap maintained with the adjacent vehicle. Lateral distribution of vehicles observed under different traffic conditions is presented in Figures 2 to 6. Detailed procedure used in finding the effective vehicle width is shown in Figure 1. Once the gap data is obtained, relationship between lateral gaps and area occupancy is established. These relationships would be used in varying the cell width, depending on the traffic conditions.

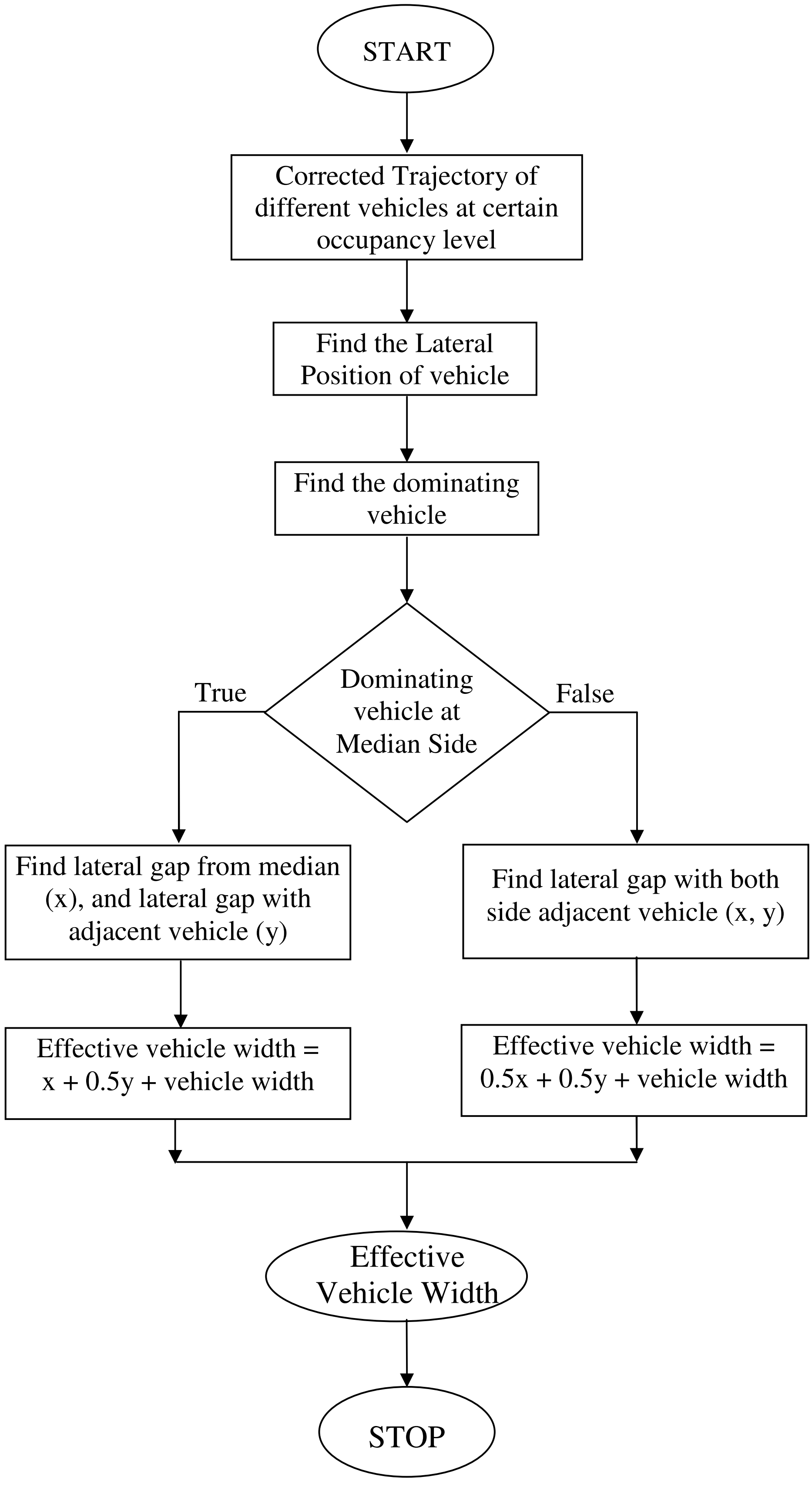

Figure 1: Flow chart showing the procedure about finding the effective vehicle width.

4.1.1. Lateral Distribution of the Vehicles

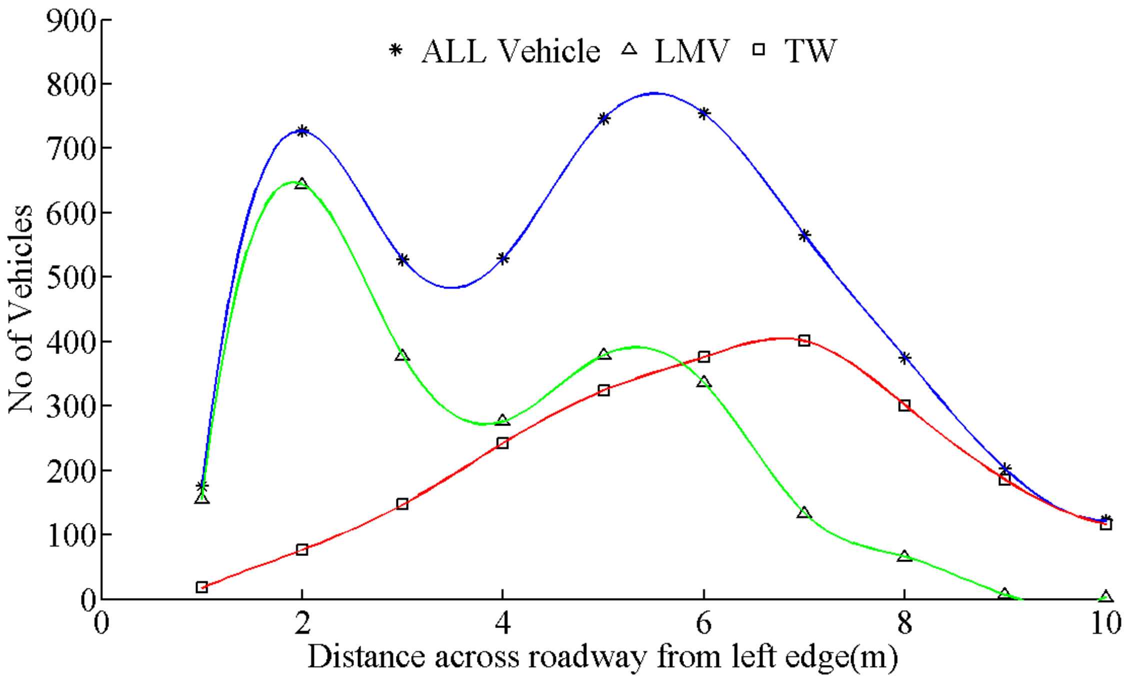

Figure 2: Lateral distribution of Vehicles observed between 8-45 and 9-45 hrs.

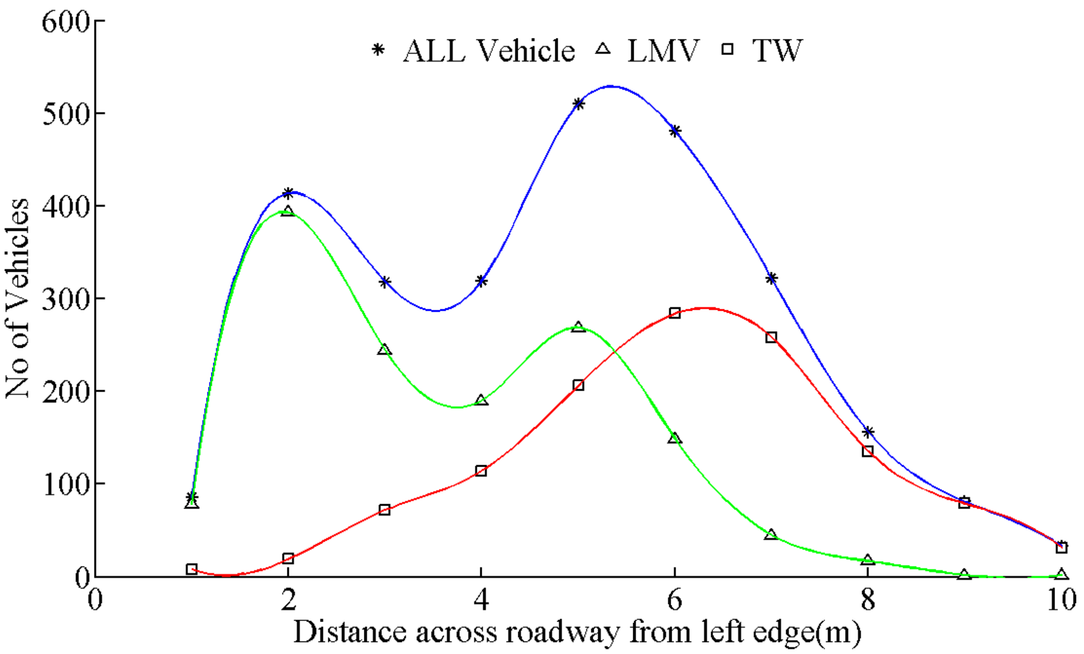

Figure 3: Lateral distribution of vehicles observed between 10-15 and 11-15 hrs.

Under heterogeneous traffic conditions, vehicles can have any lateral position irrespective of their physical and mechanical characteristics. A two lane road can have three vehicles side by side under certain traffic and road conditions. Lateral distribution of vehicles and their lateral gap maintaining behavior governs the number of sub-lanes or effective road width to be used in a CA model. When lane discipline is not strictly followed, to avoid discomfort of traveling on shoulder lanes, vehicles tend to travel away from the shoulder lane. When traffic volumes are high there is a tendency of segregation, where two wheelers tend to travel on the left side of the road. Three hours data set collected on the Dabri road and 30 min data of ring road has been analyzed. In first one hour, from 8-45 AM to 9-45 AM around 4000 vehicles have passed through this road section, and 2700, and 2000 in the other two hours, 10-15 to 11-15 AM and 12-15 to 13-15 PM, respectively. Lateral distribution of vehicles is shown in Figures 2 to 6. From these figures, it is clearly observed that, most of the vehicles are utilizing the available road space as if it is a two lane road.

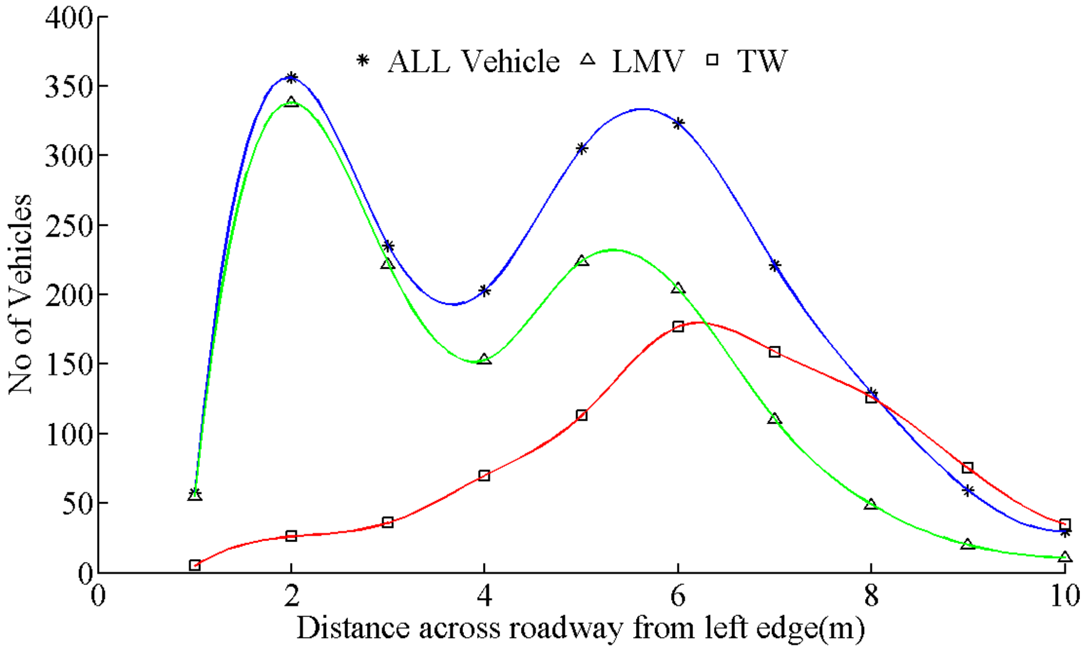

Figure 4: Lateral distribution of vehicles observed between 12-15 and 13-15 hrs.

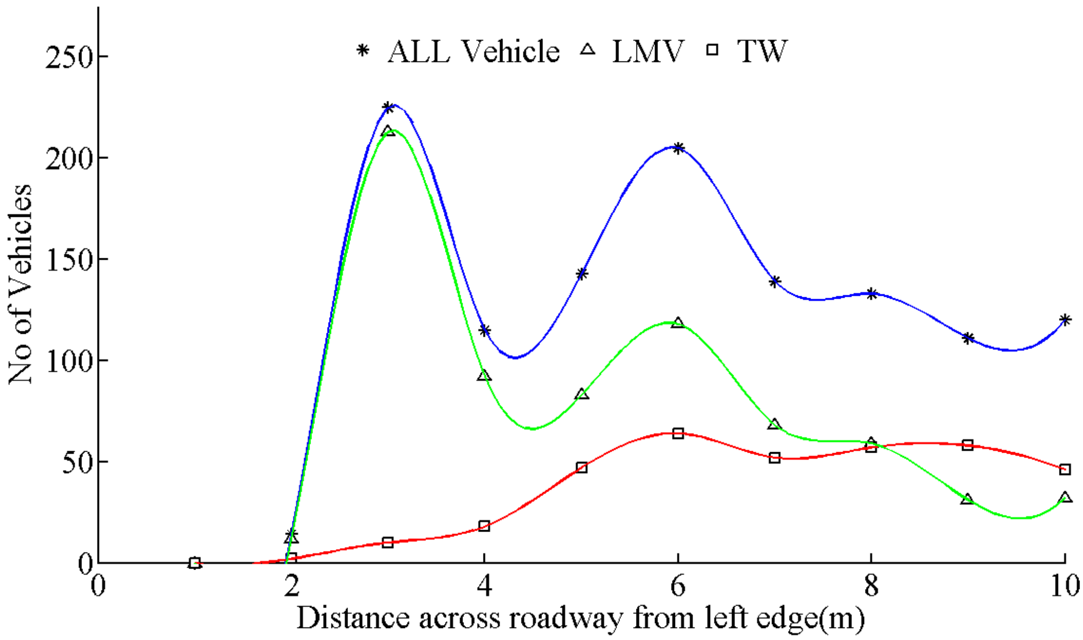

Figure 5: Lateral distribution of vehicles observed in ring road between 15.30 and 15.45 hrs.

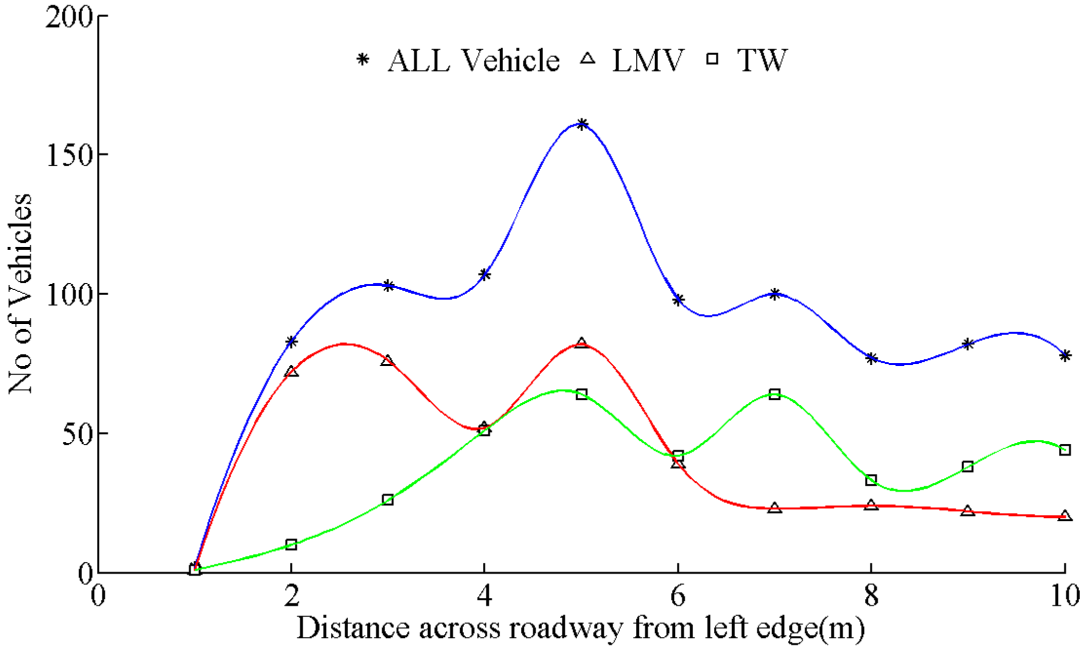

Figure 6: Lateral distribution of vehicles observed in ring road between 15.45 and 16.00 hrs.

Two distinct peaks can be observed, at around 2 m and 6 m. It is observed that most of the LMVs are travelling on the right side (near median) of the road. From the other two hours data also, it has been found that all the vehicles were utilizing the available road space like previous one hour period. From Figures 2 to 6, it is clearly observed that the lateral distribution of vehicles is varying depending on the traffic volume and composition of the traffic. At higher traffic volumes, segregation of two wheelers and LMVs are observed. From the above analysis it can be said that LMVs are dominant mode in the traffic and the position of its movement is varying with respect to the traffic conditions. For all the three hours of Dabri road LMVs are travelling close to median and on the Ring road LMVs are more or less utilizing all the three lanes evenly.

4.1.2 Lateral Gaps

Lateral gaps maintained by different types of vehicles are important in deciding the cell width. In the CA model for heterogeneous traffic, lateral gap is included in vehicle widths i.e., vehicle width in this model comprises of actual vehicle width and gaps maintained on both the sides. To utilize this characteristic in CA model, it is essential to know the variation of the lateral gaps maintained by different vehicles. It is difficult to study the lateral gap maintaining behavior of each and every vehicle under several observed traffic conditions. Hence, average lateral gap maintaining behavior of different vehicle groups is studied and presented in Figures 7 and 8. In these figures the variability is explained using a characteristic called area occupancy which was found to be better in representing the heterogeneous traffic conditions compared to density or occupancy (Mallikarjuna 2007). Due to the numerous complex interactions associated with the heterogeneous traffic, it is not easy to describe the gap maintaining behavior with varying traffic conditions.

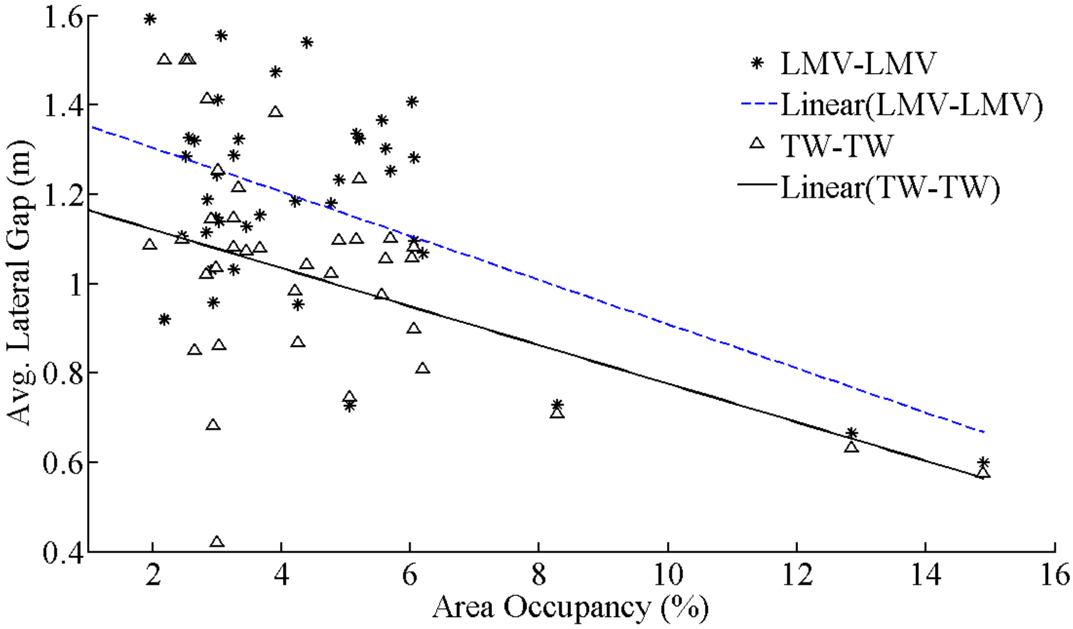

Figure 7: Influence of area occupancy on average lateral gap (m) between LMVs and TWs.

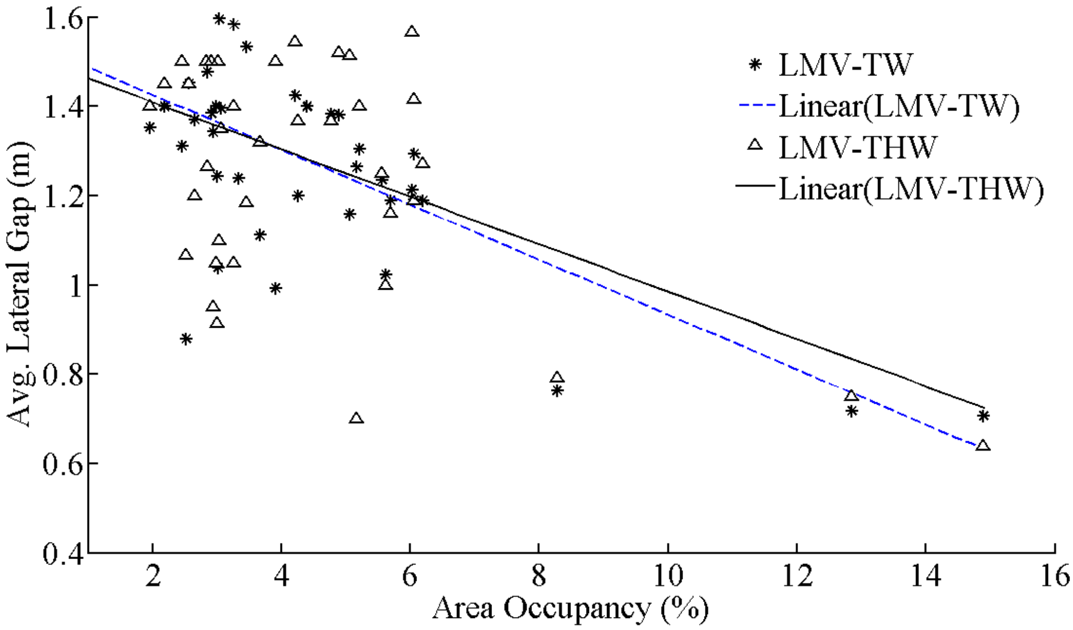

Figure 8: Influence of area occupancy on average lateral gap (m) between LMV-TW and LMV-THW.

The influence of an important traffic characteristic known as area occupancy on lateral gap maintaining behavior of vehicle combinations LMV-LMV, TW-TW, LMV-THW and LMV-TW are tested. In Figures 7 and 8, influence of area occupancy on lateral gap maintaining behavior of 4 types of vehicle combinations is presented. It is found that the average lateral gap is decreasing with the increasing area occupancy.

5. Cell width

The procedure used in finding the cell width is shown in Figure 1. As shown in this figure, clearances maintained with the median and with the other vehicles is the key input in finding the cell width. Figure 9 shows the influence of area occupancy on mean clearance from median for different vehicle types. It can be seen that, in case of TW and HMV, mean clearance from median is decreasing as area occupancy is increasing.

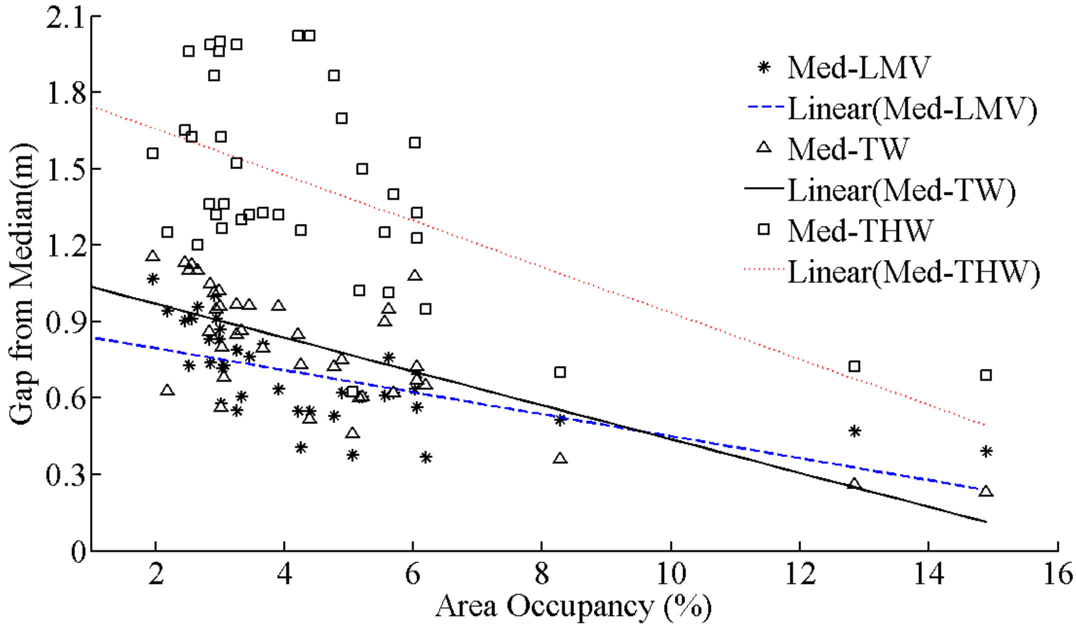

Figure 9: Influence of area occupancy on mean clearance from median for different vehicle types.

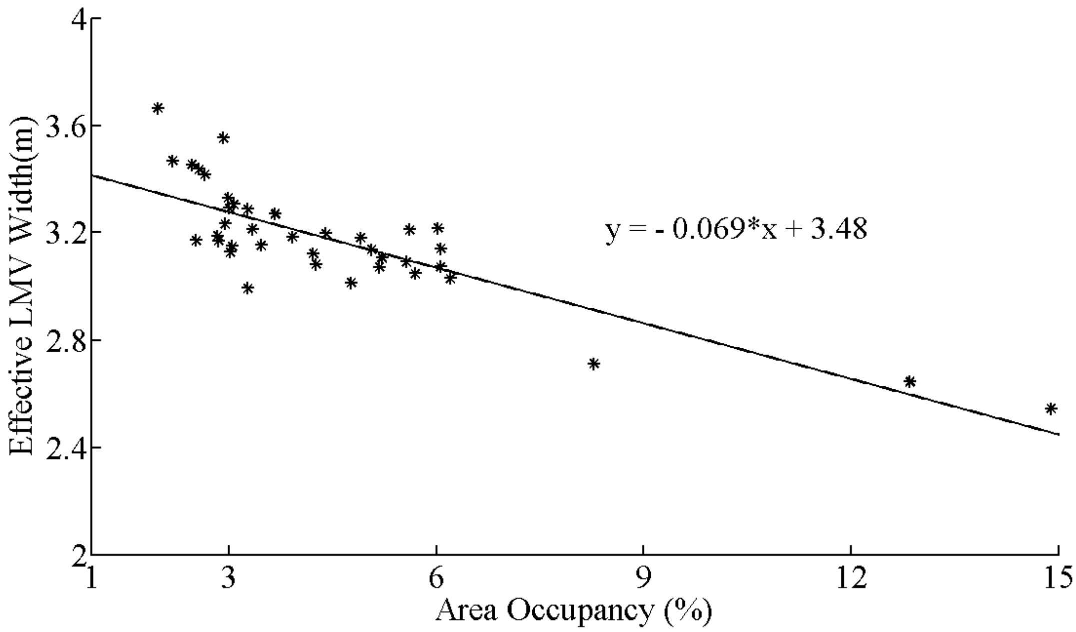

Figure 10: Variation of effective LMV width at different area occupancy levels.

Data on lateral gap maintained by different types of vehicles that has been considered in this study is the average value collected over five minute intervals. It has been found that effective LMV width decreases when average area occupancy increases (Figure 10). It is already mentioned that LMV is the dominant vehicle and its effective width is varying depending on its lateral position on the road, area occupancy, and the side vehicle. Hence, the larger value among different vehicle combinations at different area occupancy levels is taken into consideration while deciding the cell width.

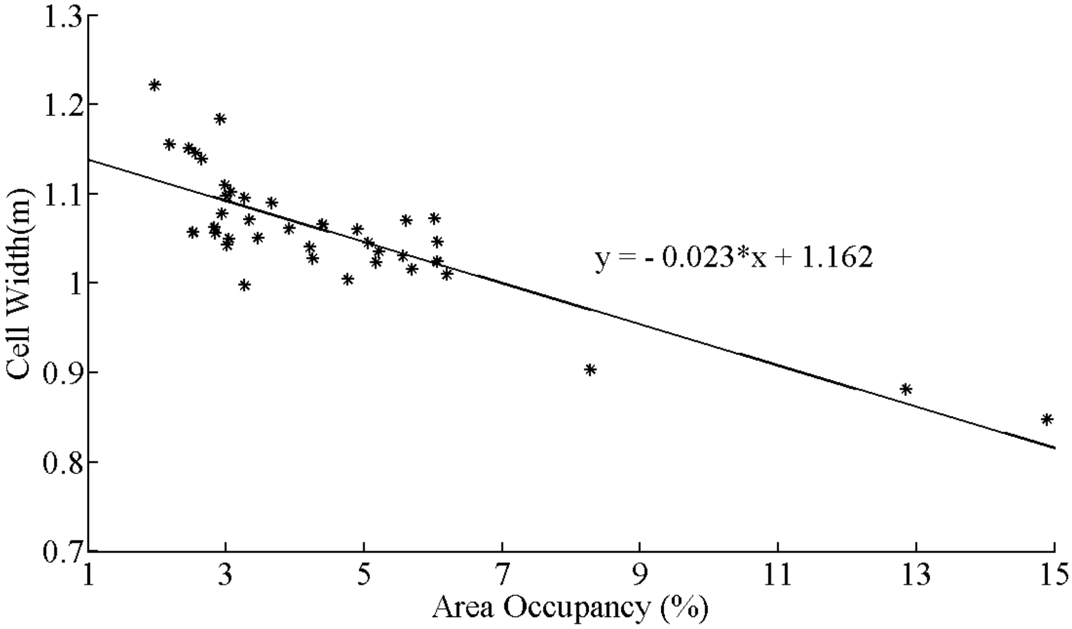

Figure 11: Cell Width (m) vs. Area Occupancy (%).

To represent all the vehicle combinations, LMV's effective width is divided by 3 and is plotted against area occupancy and is shown in Figure 11. This acceptable cell width is plotted against area occupancy to get the cell width at different area occupancy levels. Figure 11 shows the variation in cell width at different area occupancy levels. A linear regression line obtained from the cell width and area occupancy relationship is shown below.

Cell Width (in m) = - 0.0234 x Area Occupancy + 1.1652 (1)

Using the above relation, cell width (m) for different area occupancy levels is found out and shown in Table 2. This cell width has been used to find the vehicle width as well as road width in terms of cell at different area occupancy levels and shown in Table 3.

Table 2: Variation of cell width (in meter) with area occupancy.

Area Occupancy	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Cell width (m)	1.10	1.07	1.05	1.02	1.00	0.98	0.95	0.93	0.91	0.88	0.86	0.83	0.80

Table 3: Cell width and road width in terms of cells.

Area Occupancy	TW	LMV	THW	HMV	Road Width
3	2	3	3	3	9
4	2	3	3	3	9
5	2	3	3	3	10
6	2	3	3	3	10
7	2	3	3	3	10
8	2	3	3	3	11
9	2	3	3	3	11
10	2	3	3	3	11
11	2	3	3	3	12
12	2	3	3	3	12
13	2	3	3	3	12
14	2	3	3	3	13
15	2	3	3	3	13

6. Conclusions

In this study, microscopic data such as lateral gaps between adjacent vehicles, median, and lateral distribution of vehicles have been analyzed. It has been found that volume of LMVs is higher in all the three cases, and hence, LMV is the dominating vehicle. Data of three hrs of Dabri road shows that most of the LMVs are passing nearby median and the 15 minutes of ring road data shows that most of the LMVs are passing through the middle of the road. This information is used in deciding the effective vehicle width. Finally, the cell width has been decided on the basis of the effective width of the dominating vehicle at different area occupancy levels. This cell width is used in finding the vehicle width in terms of cells. It is observed that the vehicle width as well as the road width in terms of cells is varying when area occupancy is increasing from 3 to 15%. This information indicates that lateral gap maintaining behavior of vehicles is important in deciding the structure of the cellular automata based traffic flow model and this is more significant when developing the heterogeneous traffic flow models covering various traffic conditions.

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