Analysis of the Effect of Variable Lateral Gap Maintaining Behavior of Vehicles on Traffic Flow Modeling

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Abstract

Vehicular interaction between different types of vehicles, in both the lateral and longitudinal directions, significantly affects the heterogeneous traffic flow modeling. From the field data it has been observed that the drivers vary gaps based on the changing traffic conditions. This variable gap maintaining behavior has been characterized using macroscopic traffic characteristic called area occupancy. Variable gaps are explained through effective vehicle width and it is found to be influenced by various factors. In this study, variable gap maintaining behavior is modeled using the concept of cellular automata (CA), with the help of a modified cell structure. Cell width in the modified cell structure has been varied corresponding to the observed variation in the effective vehicle width. It was found that the results obtained from the model incorporated with the variable gap maintaining behavior are significantly different from that of the uniform-cell-width based CA model. The effect is more significant for urban traffic conditions due to the presence of two-wheelers and three-wheelers.

Keywords: Cellular automata; Heterogeneous traffic; Lateral gap; Variable cell width; Cell structure.

1. Introduction

Wide ranging physical dimensions, weight, and other dynamic characteristics of vehicles characterize the heterogeneous traffic observed in developing countries like India. The driver, under these conditions, can utilize any space available on the road without any lane discipline. When different types of vehicles share the same road space without any lane discipline, the extent of vehicular interactions varies widely with the variation in traffic mix and

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traffic conditions. It also generates significant level of friction or frictional clearance between the vehicles moving side-by-side in the traffic stream. This frictional clearance is expressed in terms of lateral gaps maintained by vehicles. The lateral gap may vary depending on the type of vehicle, vehicle size, speed, area occupancy, etc. Under heterogeneous traffic conditions, at higher traffic volumes, a large proportion of motorized two-wheelers and bicycles are able to move with speeds closer to their free speeds because of their ability in utilizing the smaller gaps in the traffic stream. Modeling these traffic conditions require systematic study of all the relevant characteristics of traffic, with enough data support. From limited field observations, Pal and Mallikarjuna [1] have shown the variation of the average gaps maintained by vehicles with respect to area-occupancy. These relationships are valid for only specific traffic conditions. There is a need to extend these relationships for studying different traffic conditions prevalent on the roads. It is also necessary to incorporate this variable gap maintaining behavior in traffic flow models.

Cellular Automata concept is being widely used to model the heterogeneous traffic streams. CA model used for homogeneous traffic requires modifications to the CA structure as well as updating procedures in both lateral and longitudinal directions. To model no lane-discipline which can be attributed to the driver discomfort as well as due to the presence of small sized vehicles, the present concept of lanes may not be useful. It is necessary to include lateral gaps at different traffic conditions in addition to actual vehicle width while deciding the CA structure. The cell width must be decided in such a way that the small vehicles such as motorized two wheelers and three wheelers are represented appropriately. The cell structure must incorporate the variable gap maintaining behavior of different vehicles under different traffic conditions. Fig. 1 and 2 show the traffic conditions at different occupancy levels over a 13m wide road located in Motibagh, Delhi, India, at 14.30 hrs and 14.40 hrs, respectively. It is clear from these figures that more number of vehicles can move on the same road section at a different occupancy level.

In this paper, variable gap maintaining behavior of vehicles is modeled using CA concept with a modified cell structure. Cell widths have been varied corresponding to the variation in the lateral gaps observed in the field data. The observed variation in the lateral gaps has been captured and incorporated in the model using macroscopic characteristic called area occupancy [2]. Area occupancy is a variant of occupancy that is commonly used in traffic flow theory. It expresses for how long a particular size of the vehicle is moving on a certain area of the road. Whereas, occupancy is the percentage time the road section is occupied by a vehicle over a given period of time. Area Occupancy can be measured over time and over space. In this study, temporal area occupancy is used for the analysis of gap maintaining behaviour and is termed as area occupancy throughout this paper. Effect of variable gap maintaining behavior has been studied using flow-occupancy relationships and it has been found that the reduced lateral gaps at higher occupancy levels significantly affect the resulting flow values. The effect of the variable gap maintaining behavior is more predominant in urban traffic scenarios due to the presence of smaller vehicles such as two-wheelers and three-wheelers.

This paper is organized into five major sections. In the next section background literature is presented. Section 3 describes the data collection methodology and the process of determining the variable cell width. Section 4 deals with the description and validation of the CA based simulation model. Summary and conclusions are presented in last section.
2. Background Literature

This review is more on how the gap related data has been used in different microscopic traffic flow models developed for heterogeneous traffic conditions. Some of the works carried out using cellular automata concept are also reviewed. Many researchers in the past have analyzed the heterogeneous traffic conditions with the help of microscopic models. In many of these works vehicular movements are modeled using explicit gap maintaining behavior and movement pattern of vehicles, observed in the field data. Some researchers have tried to study the gap maintaining behavior with respect to macroscopic traffic variables like flow, speed etc. Tuladhar [3] has studied longitudinal and lateral clearances for determination of influence areas of vehicles. Nagaraj et al. [4] investigated the linear and lateral placement of the vehicles in the heterogeneous traffic to develop models for mixed traffic flow. They have done extensive data collection studies on gap maintaining behavior of vehicles. Data on lateral and longitudinal gap maintaining behavior were collected on a two lane undivided road catering to the bidirectional traffic.

Anjaneyulu [5] used neural networks to model the relationships between lateral and longitudinal spacing of vehicles and the traffic volume. Singh [6] 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 spacing from the physical barriers like kerb, median etc. Gundaliya [7] has developed three CA based models for modeling the heterogeneous traffic streams. In case of first two models namely single and two lane heterogeneous traffic flow models, a constant cell width of 5.0 meter was used irrespective of traffic conditions. In the third model, for simulating no-lane discipline traffic conditions, 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 even though it was known that the lateral gaps vary with traffic conditions. Gundaliya et Al. [8] have proposed a grid based modeling approach to cellular automata. The road space is divided into a grid of equally sized cells. Lan and Chang [9] used different lateral gaps maintained by cars and two-wheelers in deciding the cell size. Since two-wheelers are maintaining a lateral spacing of 0.45 m on left and 0.4 m on right, they took the cell width as 1.25 m. These lateral spacing values are meant for speeds less than 55 km/h. Mallikarjuna and Ramachandra Rao [10] 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 an 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 traffic flow model. The cell width was constant irrespective of occupancy, which is a limitation of this model. Mallikarjuna and Ramachandra Rao [11] incorporated the lateral gap maintaining behavior in the CA model for different combinations of vehicles. They have shown the cell structure for different occupancy levels. Same road section can be occupied by different number of vehicles depending on the traffic conditions. Lan et al. [12] have studied the erratic behavior of two wheelers. In addition to the conventional moving forward and lane-change rules, this CA model also explicated the lateral drift behavior for cars and motorcycles moving in the same lane. Gunay [13] found that more frictional clearances are required with the increasing speed of passing vehicles. 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. [14] developed a simulation model for modeling mixed traffic flow on two-lane roads. They found that the 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. In most of these studies effect of gap maintaining behavior has been modeled with some limitations. Inadequate data was found to be the major reason for these limitations. Moridpour et al. [15] have shown the effect of surrounding traffic characteristics on lane changing behavior. They have analyzed lane changing manoeuvres’ of 28 heavy vehicles and 28 passenger cars and found the variation in lane changing behavior of both type of vehicles. They have observed that heavy vehicles speed changes little during a lane changing manoeuvre. Heavy vehicle drivers mainly move into the slower lanes to prevent obstructing the fast moving vehicles which approach from the rear. However, passenger car drivers increase their speed according to the speeds of the lead and lag vehicles in the target lane. They more commonly move into the faster lanes to gain speed advantages. Mallikarjuna et al. [16] have observed that the lateral gap maintained by a particular vehicle type also depends on the speed of the side vehicle. Luo et al. [17] have observed a linear variation between lateral distance from the surrounding objects and the speed.
of the passing car. The surrounding objects were shoulder on left side and bicycle on the right side. This study was limited to analyze the interaction of car and bicycle only.

Hence the main objective of this study is to incorporate the variable lateral gap maintaining behavior of vehicles through variable cell width in the CA based traffic flow models and to analyze the effect of these changes through flow-occupancy relationships.

3. Data analysis and determination of variable cell width

Data used in this study have been collected near two locations, viz., a mid-block section of the Dabri road near Delhi-Noida-Delhi (DND) flyway, connecting Delhi and Noida, and a rural highway connecting Delhi and Amritsar. Data collected on DND flyway is composed of LMV (Light Motor Vehicle), MTW (Motorized two wheeler), HMV (Heavy Motor vehicle) and MThWs (Motorized three wheeler (Auto)) and their proportions were 52%, 43%, 4% and 1% respectively. 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. Image processing software TRAZER was used to process the video film and manually collected trajectory data was used for correcting the trajectories obtained from the TRAZER [18]. The road stretch of 50 m length was used for manual trajectory data collection. The road was divided into a grid of 1m x 1 m size with adhesive cello tape. The video of the vehicles moving over the grid was recorded and was run in the laboratory on a big screen frame by frame and the trajectory data was collected. The essential microscopic data related to the gap maintaining behavior has been extracted from the corrected trajectories. Various other data related to the microscopic characteristics such as lateral gaps, difference in lateral positions of various groups of vehicles were derived from the trajectory data. The second data set has been collected on a rural highway connecting Delhi and Amritsar. Important characteristic of rural traffic is the composition of heavy vehicles such as trucks and LMVs in the traffic stream. Around 15% of heavy vehicles have been observed in the traffic stream. Road width in this section is about 7.5 m and in the simulation model it has been considered as 7.4 m.

3.1. Microscopic Data

It has been observed from the data that the lateral distribution of vehicles is varying depending on the traffic volume and composition of the traffic. It is also seen that LMVs are dominant mode in the traffic and the position of its movement is varying with respect to the traffic conditions. Pal and Mallikarjuna [1] has shown the lateral distribution of vehicles on varying traffic conditions as well as the variation of lateral gaps of different vehicle combinations in different traffic conditions. The effective vehicle width is the sum of physical width of vehicle, lateral gap from median and half of the lateral gap with adjacent vehicle. Details procedure used in finding the effective vehicle width may be found in Pal and Mallikarjuna [1]

![Fig. 3. Cell Width (in m) vs. Area Occupancy (%).](image)
3.2. Cell Width

Average lateral gaps maintained by different types of vehicles have been collected for each five minute interval. These gaps have been utilized in finding the effective vehicle width. It has been found that the effective LMV width decreases when average area occupancy increases. Since the LMVs are dominant in the traffic stream, cell widths used in the CA model are obtained based on the effective LMV width. The relationship obtained between area occupancy and cell width is shown in Fig. 3.

A linear regression line obtained from the cell width and area occupancy relationship is shown in equation 1.

\[
\text{Cell Width (in m)} = -0.023 \times \text{Area Occupancy} + 1.1616
\]  

(1)

Using the relation given in equation 1, cell width (in m) for different area occupancy levels is estimated. This cell width has been used to find the vehicle width as well as the road width in terms of cells at different area occupancy levels. Area occupancy more than 15% is not analyzed in this study and it is assumed that the minimum cell width is 0.80 m even if the area occupancy is more than 15%.

4. Validation of the simulation model

CA model proposed by Mallikarjuna and Rao [10] has been used in this study with modification on the basis of varying cell widths corresponding to different area occupancy levels. Macroscopic data such as speed, flow and occupancy measured at a road section is available for two locations. Similar data has been collected from the simulation model. Validation of the simulation model using these data sets is shown in the following subsections.

![Graph](image)

**Fig. 4. Simulated and observed flow-occupancy relationship for urban traffic**

4.1. Urban Traffic

Data collected on Dabri road is utilized in validating the simulation model. Observed traffic composition, free flow speeds and road geometry are the key inputs to the simulation model. Updating methodologies and the parametric studies on the model related parameters can be found in Mallikarjuna and Rao[10]. As discussed earlier, near this location the road is of 10 m wide. From the lateral distribution of vehicles it has been observed that about 8 m road width was being utilized by the vehicles and the same information is utilized in the simulation model. Flow, speed and occupancy obtained for each one minute interval, collected over a period of three hours has been utilized in validating the simulation model. Observed and simulated flow-occupancy relationships resulting from the uniform-cell-width CA model and the modified model are shown from Fig 4. From this figure it can be said that the simulated data both from uniform and varying cell width models are closely matching with the observed field data.
It also can be said that, observed data is limited to certain occupancy range only and validity of this model is limited to this range. This is true, since lateral gaps maintained by different vehicles are only available for certain range of occupancy levels. At similar occupancy levels, R-square value obtained between the observed flows and the output of uniform cell width model is 0.795, whereas this is 0.875 for observed data and the output of the variable cell width model. This indicates that the variable cell width is able to explain the variability in the observed data in a better way.

4.2. Rural Traffic

Flow, speed and occupancy obtained for each one minute interval collected over a period of one hour has been utilized in validating the simulation model for rural traffic. Fig. 5 shows the flow-occupancy relationships obtained from observed data and simulated data from both the modified and uniform-cell-width CA models. It is clearly observed that in both the cases, the relationship between flow and occupancy by manually collected data and data obtained by simulation model is closely matching. At similar occupancy levels, R-square value obtained between the observed flows and the output of uniform cell width model is 0.65, whereas this is 0.786 for observed data and the output of the variable cell width model. This indicates that the variable cell width is able to explain the variability in the observed data in a better way.

![Fig. 5. Simulated and observed flow-occupancy relationship for rural traffic](image_url)

5. Summary and Conclusions

In this study, variable gap maintaining behavior of vehicles, moving in heterogeneous traffic streams, is modelled using a CA based traffic flow model. Variable gap related data are utilized in finding the effective vehicle widths under different traffic conditions. 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 has been used in finding the number of cells associated with different vehicles as well as road width. Effect of the variable gap maintaining behavior has been studied on two different traffic streams namely rural and urban. Important conclusions drawn from this paper are listed below:

- Vehicles moving in heterogeneous traffic streams maintain variable lateral gaps and this behavior is explained using macroscopic traffic characteristic called area occupancy.
- Lateral gap is incorporated in the CA based traffic model using variable cell width which affects the road and vehicle widths in terms of cells.
- Both the uniform-cell-width and variable-cell-width based CA models are validated using observed macroscopic data from rural and urban traffic conditions.
• It is observed that at lesser occupancy levels flow-occupancy relationships resulting from both the models are comparable. At higher occupancy levels, there is a pronounced effect of variable gap maintaining behavior.

• When traffic is composed of more numbers of smaller vehicles such as motorized two-wheelers and three-wheelers, which can be observed in urban traffic streams, the effect of variable gap maintaining behavior is more prominent. In case of rural traffic, due to the lesser numbers of smaller vehicles, difference in the results is not that significant.

**Future Work**

More data, related to different traffic conditions from different road sections are to be collected to further establish the lateral gap and area occupancy relationship. To know the exact effect of the traffic composition, again more data covering various traffic streams are to be collected. Data related to area occupancy more than 15% are required to be analyzed.

**References**


