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Modelling of Seepage Behaviour Using Available Gaps at Signalized Intersection

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Abstract

Seepage behaviour is identified by the movement of two-wheelers from back of the queue in a signalized intersection to the front through small gaps between other vehicles. In mixed traffic, this is a common phenomenon when the signal turns red. This study attempts to model seepage using Cellular Automata (CA) based simulation. These interactions between the vehicles affect the safety and capacity of a facility. There are very few studies that include this behaviour in the CA based models. This study further calculates lateral and longitudinal gaps available between adjacent front and side vehicles to identify the forward movement possibilities. The study is compared with the simulation software VISSIM. It is evident that the software is unable to replicate the seepage behaviour, which is reflected in the trajectories.

Keywords: Seepage; Interaction; Cellular Automata (CA); Gaps; Creep

1. Introduction

Traffic signals are important components of roads. The modelling of heterogeneous traffic at signalized intersections is a complex task. Signals are useful when traffic is more; else roundabouts are sufficient (Kakooza et al. 2005). While simulating the signalized intersection, several characteristics are to be considered. Some of these characteristics are interaction between the vehicles, driver behaviour, emissions, seepage, heterogeneity etc. Two-wheelers show a unique role at the intersections, they are not much affected by the neighbouring traffic, but they affect other traffic. When the signal is red, two-wheeler creeps into the small spaces between other vehicles and reach at the

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beginning of the intersection; this behaviour is called seepage. Fig. 1 shows the seepage behaviour at intersection in the field. Seepage is described into two parts: one is named as lane filtering and another as lane splitting. When two-wheelers move through stationary traffic it is known as lane filtering while when two-wheelers move through moving traffic it is known as lane sharing (Federation of European Motorcyclists' Associations (FEMA) 2009). It has been proved in the studies that two-wheelers affect the capacity, (Federation of European Motorcyclists' Associations (FEMA) 2009) saturation flow rate, headway (Adams et al. 2015) and safety (Ambarwati et al. 2014). Moreover interaction of vehicles can be used to calculate PCEs of vehicles (Arasan and Arkatkar 2010).

Fig. 1 Seepage behaviour at an intersection in Delhi

Cho and Wu (1994) modelled a motorized traffic which contained lateral and longitudinal movement models. Longitudinal model is used to decide reasonable speed, whereas lateral model provides desired lateral space. This study was the starting of research of mixed traffic flow, and it was helpful for development of self-consistent macroscopic and microscopic mixed traffic flow. Oketch (2000) demonstrated the methodology to simulate the non-motorized vehicles in a heterogeneous traffic. The seepage behaviour of two-wheelers can be seen in the Fig. 2. Lateral movement rules were also introduced such that the maneuvering of vehicles happens gradually. A field survey based deterministic simulation model was built by Lan and Chang (2005) to explain the interaction between two-wheelers and cars. This model was further extended to stochastic simulation, and then relationship between flow, occupancy and speeds were explained.

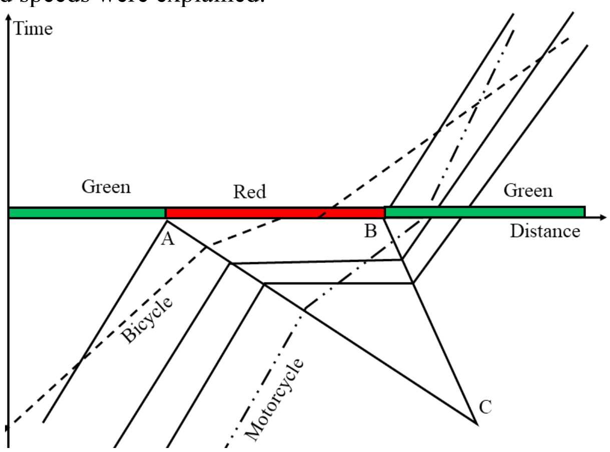


Fig. 2 Time-distance diagram showing seepage of narrow vehicles (Source: Oketch (2000))

Agarwal and Gregor (2014) have tried to simulate the seepage behaviour in their study using agent-based simulation. The Author classified vehicles into two categories, named as seep vehicles and non-seep vehicles. Each time at the intersection, if the signal is red then seep vehicles are sent to the front of the intersection irrespective of the gap availability. This procedure may not represent the field seep behaviour because seep vehicles (two-wheelers) go to the front using the spaces available between other vehicles. If the gap is not available then they stay at their respective position.

Another study by Nair et al. (2011) presented a porous flow approach to model heterogeneous traffic system of two classes using finite difference approximation scheme. This study modelled traffic macroscopically and viewed traffic system as granular flow through pores. Further, the author expanded LWR theory for heterogeneous traffic with the help of new speed-density relationship. The experimental verification of the model developed by Nair et al. (2011) was done by Ambarwati et al. (2014). Both studies modelled pore size distribution and pores were taken as triangulated edge of vehicles. A critical pore size was also calculated using driver choice indicator. Moreover, probability of desire to creep with respect to speed and pore size was determined, different sizes of pores were required with different speeds. It can be noticed that that the pore size taken was triangular distance between boundaries of the two vehicles. Nguyen et al. (2014) evaluated the traffic conflict of two-wheeler in a non-lane based congested traffic. A mobility force model similar to gravity force model was given by Hsu and Chen (2015). In this study, author assumed that in the desire of driver to move the vehicles at higher speeds (or desired speed), driver would like to be at an unoccupied place. Thus, neighbouring unoccupied spaces are attraction forces for vehicles. This study combined social force model and force field model and developed a mobility force model for motorcycle traffic behaviour.

Classical approaches to analyse mixed traffic flow comprise more recalibration exercise and have limited applications. Reasons could be that these models are mainly based on homogenous traffic conditions (Oketch 2000). Also, many of the studies mentioned above are developed macroscopically. However, the present study shows a microscopic model of simulation owing to its advantage in terms of explaining the individual vehicular movements. Further, the present study evaluates existing cellular automata (CA) models and tries to provide a methodology for simulating seepage behaviour using CA. CA models are used because they are computationally efficient and useful in modelling simple and complex simulation models (Talia 1997). A number of studies have simulated traffic junctions using CA, but none of them have included seepage in their studies (Biham et al. 1992; Chowdhury and Schadschneider 1999; Deo and Ruskin 2014; Fouladvand et al. 2004; Nagatani and Seno 1994). Ren et al. (2016) developed a simulation model which uses available spaces to reach at the beginning of intersection. In this model, a special bicycle lane was also modelled. A review was done by Das and Maurya (2017)for modelling of two-wheeler. Most of the studies done so far are for homogenous traffic with lane-based traffic; thus the seepage phenomenon was not necessarily happening in their studies, but while simulating the heterogeneous traffic with multiple lanes vehicles will have different sizes, and they will move in between the pores available between other vehicles.

Rest of the paper is presented in three sections. Section 2 presents details of the simulation modelling methodology; Section 3 presents the results from the model in comparison with VISSIM. Section 4 gives the details

2. Simulation Methodology

In one of the recent study a model by Pandey et al. (2017) on position preference-based CA model for mid-blocks, it was able to replicate the heterogeneous traffic behaviour, This model adapted for simulating traffic at signalized intersection. Following inputs were taken into consideration. This study does not follow conventional car-following theory, in conventional car-following theory, vehicles follow the centerline of the lead vehicle, but in present model, vehicle can follow a staggered path without following a particular vehicle (Fig. 3). Following inputs are needed in the model.

1. Cell sizes were taken as 0.5m in longitudinal direction and 0.7m in lateral directions. Thus the size of one cell was 0.5*0.7m. Hence width of the road with two-lane will have 10 cells in lateral direction, and if the road is 1000m then, 2000 cell will represent the length of road.
2. Vehicle Sizes: Sizes of the vehicles were taken from the study by Pandey et al. (2017) and these are shown in following Table 1

Table 1 Vehicle sizes taken in simulation

	2Ws	3Ws	Cars (LMVs)	Bus (HMVs)
Length (cells)	4	6	7	25
Width (cells)	1	2	3	4

3. Proportion of vehicles: proportion of vehicles was observed in the field and given as input.
4. Number of legs to be simulated: present model is able to replicate mid-block, T-Junction or a four-legged intersection. But here a four-legged signalized junction is considered.
5. Signal type and cycle timings: it needs to be specified if the junction is signalized or un-signalized. Further, in case of signalized intersection cycle times needs to be specified.
6. Density on each leg: density on each leg can be same as observed at the field.

Following Fig. 3 shows the snapshot of intersection simulation.

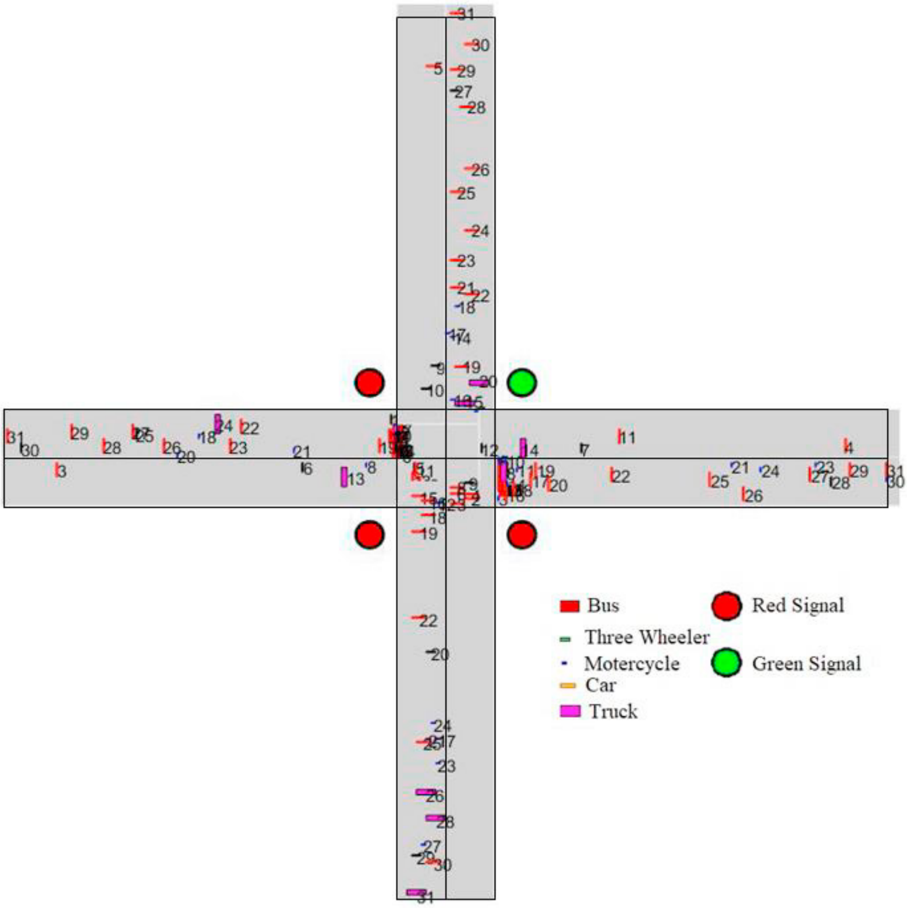


Fig. 3 Snapshot of intersection simulation

Signals and seepage behaviour was introduced in the model. Seepage behaviour was introduced when the front vehicles are moving with less speed than the follower or if there is a signal before the follower vehicle. Fig. 5 can be used to understand the methodology of seepage behaviour modelling in CA model. At any instance of time when the signal is red and vehicles are stopped before the intersection then some spaces are left by the bigger vehicles such as cars, trucks and buses etc. If this space is sufficient to maneuver the two-wheeler, then two-wheelers creep into these spaces and reach at the beginning of the intersection. This also calculates the spaces between two vehicles and if the space is sufficient then it moves into that space and continues. A stepwise algorithm to calculate the spaces is given in Fig. 6 with following steps.

1. Calculate the lateral spaces available on both sides and longitudinal gaps

   Lateral gaps are calculated as min (d_3, d_4) and longitudinal gaps are min(d_1,d_2) (Fig. 4). These gap calculations are diffident than that in the study by Ambarwati et al. (2014), here it is considered that if sufficient lateral and longitudinal gaps are available, then vehicles would be able to seep, else they will follow the leader vehicle. If a vehicle is following several vehicles (for instance car and truck), then effective gaps as explained in study by Pandey et al. (2017) are used to choose the best option between the choices available to follow a particular vehicle (either car or truck etc.).

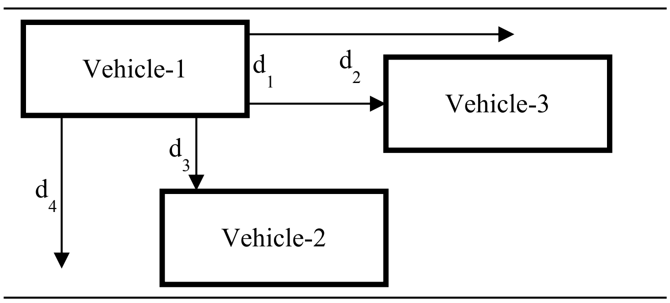


Fig. 4 Calculation of lateral and longitudinal gaps

2. If spaces are available, then vehicle checks if it can pass through the spaces with the help of comparison of its own size and gap size. If it can then it passes through the spaces and reaches to the front of the intersection, else it stays at its location till next step and the procedure continues. This phenomenon is followed by all the vehicles including cars and trucks.

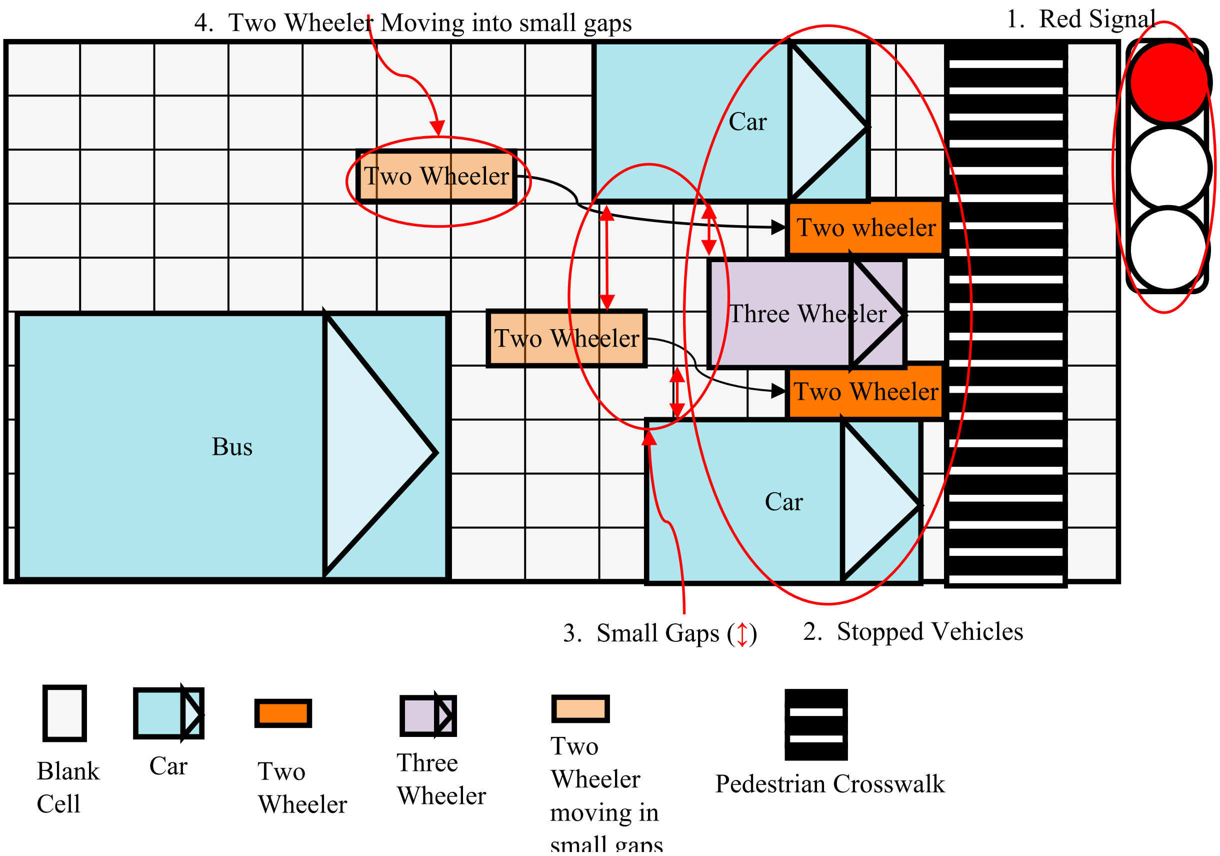


Fig. 5 Methodology to model seepage behaviour in CA model

```
Give The Size Of Vehicle
for v = 1:NumberOfVehicles
   Check Left Side Gap For vehicle(v)
   Check Right Side Gap For vehicle(v)
   Check Front Gap For vehicle(v)
   if Left Side Gap For vehicle(v) >Size Of Vehicle(v)
       Seep To Left
   elseif Right Side Gap For vehicle(v) >Size Of Vehicle(v)
       Seep To Right
   elseif Lateral position of 1st front vehicle- Lateral position of 2nd front
vehicle > size of vehicle
       Seep in-between two vehicles
   else
       Move To Front or Slow Down If No Space Is Available
   end

  end
```

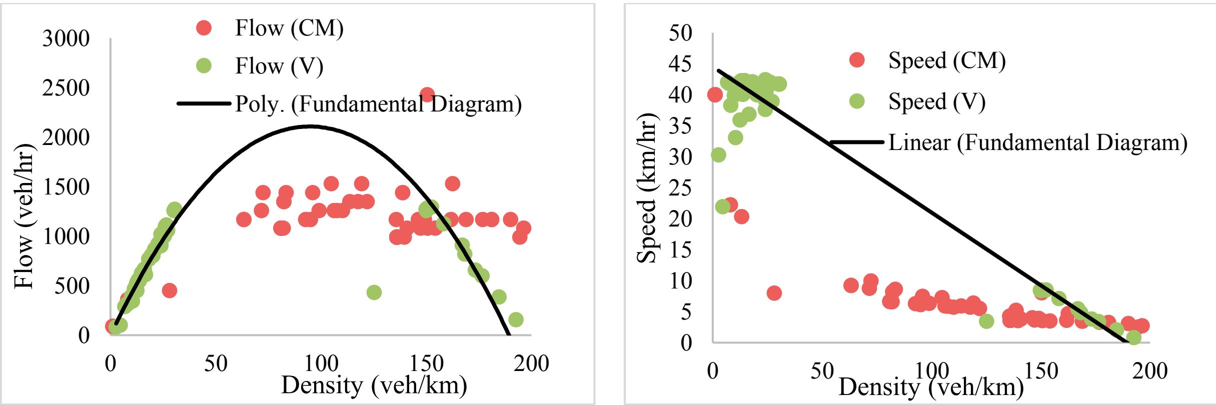
Fig. 6 Algorithm to model seepage behaviour in CA model

3. Comparison with the Simulation Model (VISSIM) – Results And Discussion

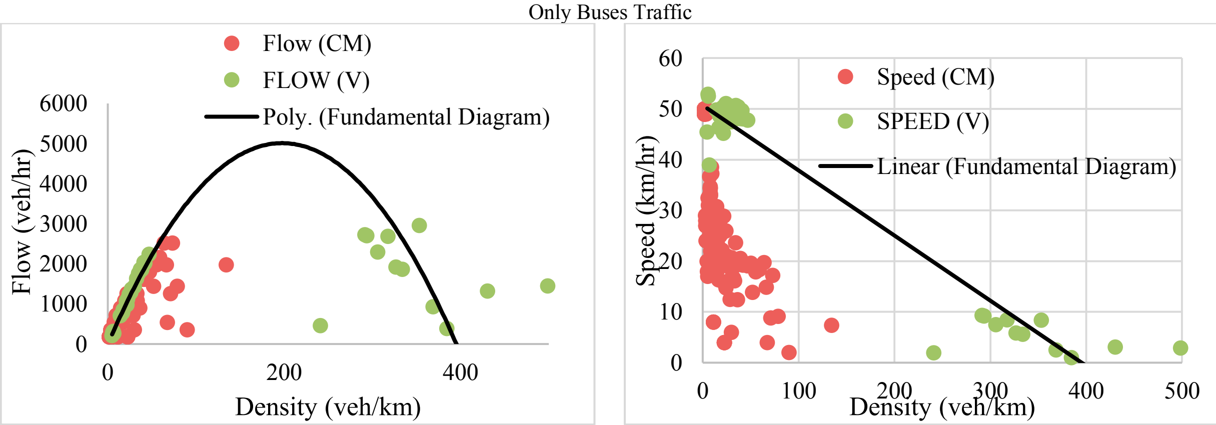
The model was validated visually and statistically using fundamental diagrams as suggested by Daamen et al. (2015). After calibrating the VISSIM with an existing Indian study by Mathew and Radhakrishnan (2010), VISSIM is used to validate the model. A model identical to present model was developed in VISSIM and data was collected at the same locations in the current model and VISSIM. While giving input of the vehicles to the models PCE values are taken from (IRC and Indian Roads Congress (IRC) 1994). It can be seen in the following Fig. 7 that fundamental diagrams concur with those using Greenshields equation (Qu et al. 2015). The parameters of the equation (free flow speed (v_f) and jam density (k_j) are calculated using linear regression between speed and density.

3.1. Validation using VISSIM

As the field data for homogenous traffic of several modes cannot be obtained to analyze the behaviour of individual modes, different cases were simulated for different modes in VISSIM. A signalized intersection similar to the current model with several modes (Bus, Car, Two Wheelers, Motorized Three Wheelers and mixed traffic condition) was modelled in VISSIM, keeping flow, speeds and mode share parameters same as in current model. Fig. 7 shows the comparative fundamental diagrams generated from these two simulation models.



Only Buses Traffic



Only Cars Traffic

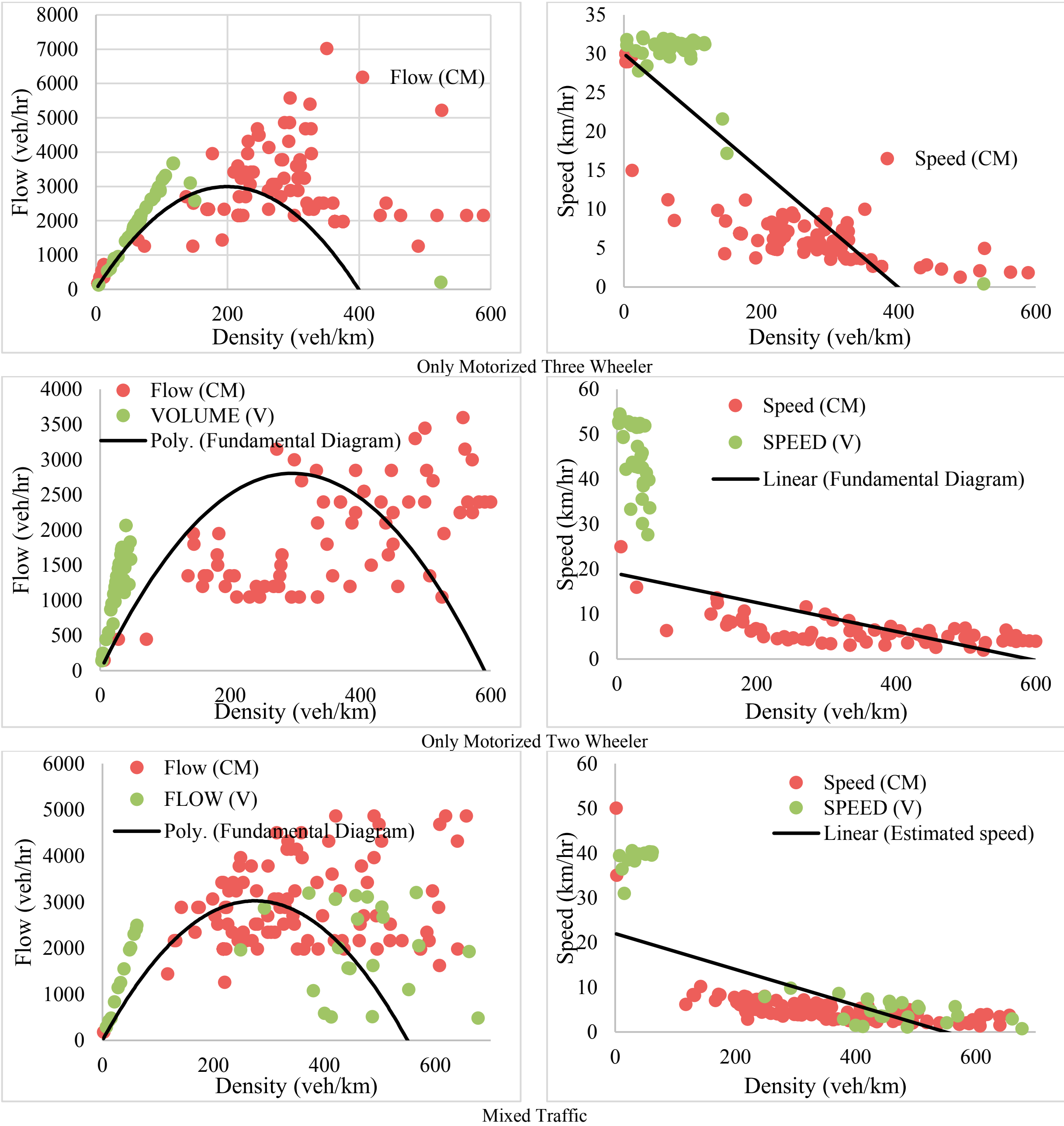


Fig. 7 Comparison of Fundamental diagrams, obtained from VISSIM and current model (CM-current model, V-VISSIM)

Simulation parameters in present study given are taken from R.K. Puram, New Delhi Intersection, these parameters are given in following Table 2

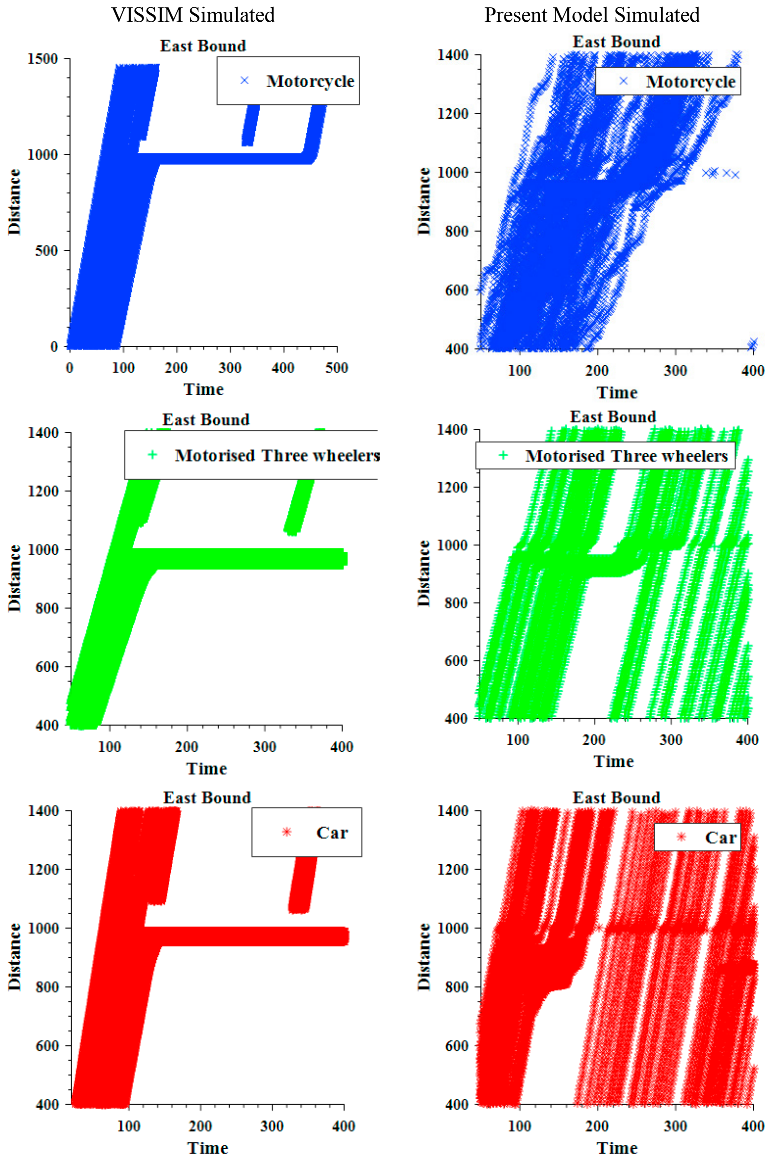
Table 2 Parameters taken into simulation

Simulation Parameters	Parameters Value
Length of each Leg	1000m
No of simulations	3600 runs
Occupancies	0.035

Cycle times	• North Bound : 120 • South Bound : 100 • East Bound :120 • West Bound : 120
Proportion and composition of vehicles	Cars: 40%, Motorcycles 40%, Trucks/Buses 4%, Motorized Three Wheelers 15%

3.2. Trajectories Comparison

Following Fig. 8 shows the trajectories plot of different vehicle types and mixed flow using VISSIM and present model simulation. Though the VISSIM model is calibrated, seepage behaviour is not observable in the VISSIM model. The trajectories of the two models were validated before the intersection using the speeds of the vehicles with paired t-test of a ‘p’ value of 0.214. The discontinuities in the trajectories generated using VISSIM are due to the connection of several links starting from beginning again (i.e., 0).



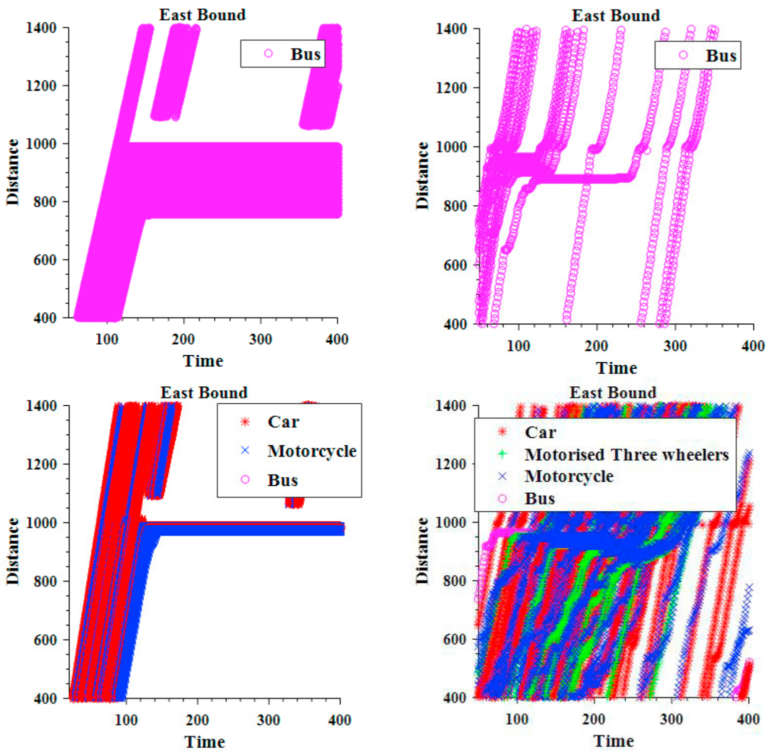


Fig. 8 Comparison of Trajectories simulated using VISSIM and present model (time is in 'seconds' and distance is in 'meters')

Fig. 8 shows stop and go behaviour at signalized intersection. The seepage in simulation is validated using distance-time (Fig. 8) plot at a signal. It can be seen that the two-wheelers have come late and moved in between other vehicles to reach at the signal. When the traffic is less vehicles are not waiting for long time while when the traffic is more they have to stand in queue and move when their turn comes.

4. Conclusions

Present model was an attempt to provide a methodology to simulate the seepage behaviour of small vehicles in traffic using CA.

- Very few studies attempt to simulate the traffic with seepage using CA, and none of them have used lateral and longitudinal gaps for vehicle seepage. In the present study lateral and longitudinal spaces are used to model seepage.
- The model developed helps to simulate the seepage behaviour. It is observed that the two-wheelers creep into the spaces between the other vehicles and reach at the front of the intersection. Model results are compared with fundamental diagrams. Trajectories are validated with speeds obtained from VISSIM and current model, using paired t-test with 'p' value of 0.214, suggesting that the speeds does not differ in both the models.
- Fundamental diagrams show that at high densities two-wheelers have lower speeds compared to other vehicles.
- At signalized intersection with non-lane based and heterogeneous traffic most of the spaces get utilized by the vehicles, because small vehicles try to seep into the spaces left by large vehicles, hence capacity increases, which is visible in fundamental diagrams.
- The trajectories also show that in the presence of seepage, lesser delays are incurred at the intersections for two-wheelers (Fig. 8).

- Further, for improvement of safety analysis, the risk behaviour of individual vehicle can be analyzed with the help of seepage behaviour (Ambarwati et al. 2014).

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