Research Article

Cellular Automata Model for Mixed Traffic Flow with Lane Changing Behavior

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Indian cities are seen with predominantly mixed traffic plying on the streets. Modeling the mixed traffic involving vehicles characterised of different speed, length, and width is a challenging issue. Based on the finer cell system of cellular automata (CA) models, this paper proposes to evaluate the mixed traffic behavior with cars and motorcycles for intermediate lane width, which is more common in Indian cities. The maximum car flow is observed (even with the presence of motorcycles) in the results which is higher than the Na-Sch model for cars. This increase is mainly due to the changing behavior. The car flow decreases as the density of the motorcycle increases. Furthermore, the paper proposes to evaluate the effect of lane change behavior on the speed and flow of the traffic stream using the fundamental diagrams of speed flow density curves. The simulation result suggests that lane change probability has little effect on the speed and flow of the traffic stream.

1. Introduction

The behavior of traffic in a multimodal system is much complex and difficult to assess. Microscopic analysis is the most scientific way to analyse these traffic situations, since it considers each vehicle as an individual and can model collective phenomena of traffic flow. Cellular automata (CA) models are widely used traffic simulation models because of their simplicity [1]. Due to their fast performance when used in computer simulation, CA models are considered more advantageous over other models [2]. The idea of CA was started by Johann Louis von Neumann in 1948, when he used them to study living biological systems [3]. The CA were more popularised in the nineteen eighties by the works of Stephen Wolfram [4]; he related CA models to all disciplines of sciences. Mainly, there are three kinds of CA models: stochastic models, deterministic model, and slow to start models. In 1992, Nagel and Schreckenberg proposed a CA model that can reproduce the most characteristics of traffic flow [5]. It is a stochastic model widely called as Na-Sch model.

The Na-Sch model was further improvised in order to reproduce more realistic phenomenon of traffic. Biham and Middleton proposed a model for two dimensional traffic flows [6]. The three-phase transition model was proposed by Kerner and Klenov in 2002 [7]. Based on the KKW model, breakdown scenario was proposed by Tian et al. [8]. The major advance in CA models was proposed by Nagatani for the lane changing behavior on the traffic flow [9]. Researchers presented the review of both particle hopping models along with fluid dynamic traffic flow models [1, 10]. Other extensions to these models like the inclusion of pedestrian interaction [11–14], speed breakers [15], and bidirectional movements [16] were used for traffic flow analysis. Maerivoet and Moor [4] presented a complete review of different cellular automata models.

The regular CA model considers a single kind of vehicle for the analysis. However, in most of Asian countries, road traffic consists of mixed traffic flow. In India, the traffic composition consists of different kinds of vehicles such as motorcycles, auto rickshaws (three wheelers), cars, buses, trucks, and even animal-driven vehicles. This mixed flow is composed of vehicles with different sizes, speeds, capacities,

and acceleration capacities. The involvement of mixed traffic in the CA models is essential in order to exactly simulate the traffic condition in these parts of the World. Studies on mixed traffic flow analysis using CA models are very limited [16–19] [20, 21]. These studies evaluate the effect of different size of the vehicle on the traffic flow. Ez-Zahraouy et al., 2004 computed the densities for different entry rates for two different car sizes [17]. Furthermore, different lane changing rules such as symmetric [22–24] [25] and asymmetric [26, 27] lane changing were proposed by researchers. Even studies were conducted to evaluate the effect of traffic flow on weaving section [28] on weaving areas, effect of length of weaving length, and probability of vehicle generation on operation reliability for on-ramp junction [29], accident-induced traffic behavior in weaving sections [30]. An et al. [31] studied the effect of lane allocation at weaving areas on the operational efficiency. Ricket et al. [32] presented an extension to the single-lane CA model by a set of lane-changing rules. Similarly, Yang et al. (2015) studied the traffic with the car and truck in the flow [18]. The effect of percentage composition of cycle in traffic [16], erratic acceleration, deceleration, lane changing of two-wheelers [19, 20, 24, 25], and even with non-motorised traffic [33] were studied. Meng et al. even studied the effect of two 2 wheelers moving parallel to each other on the same lane [21].

The main objective of our work is to analyse the mixed traffic condition by allowing lane changing for the vehicle at higher speeds. The CA models for mixed traffic flow analysis do consider the lane changing from left to right lane (from slower lane to faster lane) for overtaking and from right lane to left lane after overtaking to in order to allow the other faster-moving vehicles to overtake them.

In India, traffic conditions are entirely different. The traffic flow is mixed type and rarely follows any lane discipline. There is no restriction on the position of motorcycles occupying the fastest lane, unlike in China where the motorcycle cannot be ridden on the extreme left lane (left hand drive in China, Meng et al. [21]). There are possibilities of motorcycles overtaking car, and the motorcycles can maneuver either to the left or right depending upon the availability of space in front. The roads in most of the Indian cities hardly have uniform lane width and road marking. Most of the roads in Indian cities have an intermediate lane width which is marked as two lanes. Sometimes due to this, it is difficult for faster moving car to overtake a slower-moving car in front. As a result of this haphazard movement of vehicles, there will be a reduction in the capacity of the road and even results in the creation of artificial bottlenecks on the road.

An initial attempt has been made to study the effect of mixed traffic flow, particularly the effect of erratic motorcycle behavior [19]. They even considered overtaking from the left. In the analysis, they tried to include the variation of speed, length, and width of the vehicle. Both Lan et al. [19] and Meng et al. [21] used the finer cell system in the analysis by dividing single lane into sublanes. Lan et al. [19] in their analysis considered the car to occupy either to the left or right sublanes. But, in the real world, the car may occupy any position on the entire road width.

In this research, we aim to evaluate the effect of this mixed flow on the traffic characteristics and to evaluate the impact of lane changing on the speed of the vehicle. Therefore, we propose a CA model for all possible cases of mixed traffic flow condition observed in Indian cities. Here, the entire road width is divided into four sublanes, each car will occupy two sublanes, and each motorcycle occupies one sublanes. A car or two-wheeler is allowed to overtake a slower-moving vehicle in the front. The motorcycle can occupy the fastest lane, and the speed of the motorcycles can be greater than the car. Furthermore, we aim at evaluating the effect of lane changing probability on the speed and flow of the traffic stream.

2. Model

This model is the extension to the NA-Sch model allowing the lane changing for the faster moving vehicles. The stochastic model has three rules; acceleration and deceleration, randomisation, and vehicle movement, unlike in the Na-Sch model, where acceleration and deceleration are mentioned separately. The details of the Na-Sch model are given below.

The NA-Sch model [5] is defined on a one-dimensional array of size L; each cell is either empty or occupied by the vehicle. Each vehicle has an integer velocity between 0 and V_{max}. Each update as four paralleled performed operations for all the vehicles. Step 1 acceleration: if the velocity V of a vehicle is lower than V_{max} and if the distance to the next car ahead is larger than $V + 1$, the speed is advanced by one, i.e., $V \rightarrow V + 1$. Step 2 deceleration: if the vehicle at i sees the other vehicle at $i + j$ (with $j < V$), then, it reduces its speed to $j - 1$, i.e., $V \rightarrow j - 1$. Step 3 randomisation: with probability p, the velocity of each vehicle (if greater than zero) is decreased by one, i.e., $V \rightarrow V - 1$. Step 4 car motion: each vehicle is advanced V sites.

In mixed traffic flow analysis, Meng et al., 2007 incorporated overtaking opportunity from one side (right to left). They divided the lane width into three subblocks. In this model, the entire width of the road is divided into four sublanes. This is because, in India, most of the lane is neither single lane nor two lanes; they are intermediate lane which is normally in between 5-6 m. The average length of the car is considered as 4.0 m because majority of cars manufactured in India comes under the sub 4 m category and even the taxing rate of the Government emphasizes this allowing much lesser taxes when compared to the larger cars. Similarly, the average length of motorcycle is equal to 2.5 m; therefore, not more than one motorcycle can occupy the space of one car in a complete traffic jam.

The length of the road is divided into four virtual sublanes, left sublane (LSL), left middle sublane (LMSL), right middle sublane (RMSL), and right sublane (RSL) (see \re 1). Our model is defined as an array of L sites with four sublanes. Thus, the entire road becomes a two-dimensional array with 4 X L sites, then, each car occupies 2 X 1 sites and each motorcycle occupies 1 X 1 sites.

The width of the entire lane can occupy either two cars or four motorcycles in parallel. Each site will occupy one

LSL →									
LMSL →									Normal lane width of indian roads (5.0 m to 6.0 m)
RMSL →									
RSL →									

LSL–Left sub-lane RMSL–Right middle sub-lane

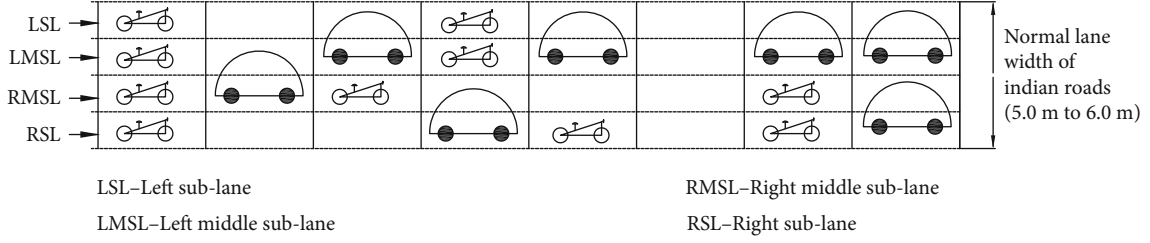LMSL–Left middle sub-lane RSL–Right sub-lane

FIGURE 1

motorcycle or one half of the car, either left or right side or otherwise the site may be empty. Two cars can occupy the entire road width, or one car occupies in any two sublanes along with a single or two motorcycles. Otherwise a single car and occupy any two sublanes without any motorcycles as shown in Figure 1.

In this model, we are using the asymmetric lane change rules proposed by Nagel et al. [27] for the analysis. The different parameters used in the model are given in Table 1.

In this analysis, the values of gap_+ and gap_- are considered as v and v_{max} as in Nagel's model [27]. The vehicle always tries to increase the speed or to maintain the existing speed while travelling. If the opportunity is there to increase its speed, the vehicle continues in the existing lane. The process of lane changing is mainly done to avoid the reduction in the existing speed of the vehicle. This means the lane changing from LSL to LMSL is triggered by slow-moving vehicle ahead in the LSL, and the next car or motorcycle in the LMSL is faster than the vehicle ahead in the LSL.

$$v_{LSL} \leq v_n^{(m)} \text{ and } v_{LSL} \leq v_{LMSL}. \quad (1)$$

v_{LSL}, v_{LMSL} are the velocities of the vehicles in the left sublane and the left middle sublane within a certain distance. If there is no vehicle in the range, the vehicles will not change lanes. Furthermore, for changing back to the original lane, we are using a slight modified model as proposed by Nagel [27]. Since in Indian, people do overtake from left the same condition prevails, i.e., the traffic on the LSL is faster than the LMSL and a slow-moving vehicle in the LMSL.

$$v_{LSL} \leq v_n^{(m)} \text{ and } v_{LSL} \leq v_{LMSL}. \quad (2)$$

The above condition holds good for motorcycle overtaking motorcycle, but for car overtaking motorcycle, a slight modification is necessary, since car occupies two sites. In this model for lane changing, we are using a conditions (1) motorcycle/car changing one sublane at a time either to its right or to its left and (2) car changing two sublane in order to over a car or motorcycle in front.

Unlike in a motorcycle where the car occupies two sublanes, the driver side (right sublane) is taken as the reference point for lane change. For cars occupying LSL and LMSL can shift to LMSL and RMSL to overtake a motorcycle travelling in LSL, the target lane will be both LMSL and RMSL. Similarly the $LR gap_+^1$, $LR gap_+^1$, $LR gap_-^1$, and $LR gap_-^2$ are calculated.

This condition prevails for all motorcycles overtaking motorcycle or car. But, the existing road width allows two cars to move in parallel, and a car can overtake another car in front, if and only if both the cars are moving in the first two sub lanes, i.e., the car occupying LSL and LMSL can move to RMSL and RSL. Similarly, a car occupying RSL and RMSL can come back to LMSL and LSL overtaking another car from the left. Therefore, $LRgap_+^3$ and $LRgap_-^3$ the target lane gaps in the front and behind are calculated.

In total, the model has two stages: movement and lane changing. During lane changing, the vehicle is moved laterally and the forward movement is given in the movement step. In total, the model has five steps; acceleration, lane changing, deceleration, randomisation, and movement, which are performed in parallel.

2.1. Step I: Acceleration.
If $dist \geq v_n^{(c)}$ and $v_n^{(c)} < v_{max}^{(c)}$ then $v_n^{(c)} \rightarrow \min(v_n^{(c)} + 1, v_{max}^{(c)})$ for car.

If $dist \geq v_n^{(m)}$ and $v_n^{(m)} < v_{max}^{(m)}$ then $v_n^{(m)} \rightarrow \min(v_n^m + 1, v_{max}^{(m)})$ for motorcycle.

2.2. Step II: Lane Changing

2.2.1. For Cars Changing One Sublane from Left to Right.
Here, a car can change the sublane from LMSL to RMSL and RMSL to RSL, since the adjacent lane is occupied by the same car. The $LR gap_+^1$, $LR gap_+^1$, $LR gap_-^1$, and $LR gap_-^2$ values change correspondingly from left to right sublanes, and suitable values were considered for lane changing.

(1) For Car from LMSL to RMSL. If $v_n^{(c)} \leq LR gap_+^1$, $v_n^{(c)} \leq LR gap_-^2$, $LR gap_-^1 \geq v_{max}^c$, $LR gap_-^2 \geq v_{max}^c$, $v_{LMSL} \leq v_{RMSL}$ and $v_{LMSL} \leq v_{RMSL}$ SS, then, car changes from LMSL to RMSL.

(2) For Car from RMSL to RSL. If $v_n^{(c)} \leq LR gap_+^1$, $v_n^{(c)} \leq LR gap_-^2$, $LR gap_-^1 \geq v_{mac}^{(c)}$, $LR gap_-^2 \geq v_{mac}^{(c)}$, $v_{RMSL} \leq v_n^{(c)}$, and $v_{RMSL} \leq v_{RSL}$, then, car changes from RMSL to RSL.

2.2.2. For Cars Changing Two Sublane from Left to Right

(1) For Car from LMSL to RSL. If $v_n^{(c)} \leq LRgap_+^2$, $v_n^{(c)} \leq LR gap_+^3$, $LRgap_-^2 \geq v_{max}^{(c)}$, $LRgap_-^3 \geq v_{max}^{(c)}$, $v_{LMSL} \leq v_n^{(c)}$, and $v_{LMSL} \leq v_{RMSL}$ or $v_{LMSL} \leq v_{RSL}$, then, car changes from LMSL to RSL.

2.2.3. For Cars Changing One Sublane Right to Left.
Here, a car can change the lane from RSL to RMSL and RMSL to

TABLE 1: Summary of the variables and parameters used in the model.

Parameter/variables	Description
$x_n^{(m)}$	Position of the nth motorcycle
$x_n^{(c)}$	Position of the nth car
$v_{\max}^{(m)}$	Maximum velocity of motorcycle
$v_{\max}^{(c)}$	Maximum velocity of car
dist	Gap between the nth motorcycle or car and the motorcycle or car in front of it
$v_n^{(c)}$	Velocity of nth car
$v_n^{(m)}$	Velocity of nth motorcycle
sp	Slowdown probability
lp	Lane changing probability
gap_+	Gap on the target lane in front of the car or motorcycle that wants to change lane
gap_-	Gap on the target lane behind the car or motorcycle that wants to change lane
LR gap_+^1	Gap on the target lane 1 in front of the car that wants to change lane from left to right
LR gap_+^2	Gap on the target lane 2 in front of the car that wants to change lane from left to right
LR gap_+^3	Gap on the target lane 3 in front of the car that wants to change lane from left to right
LR gap_-^1	Gap on the target lane 1 behind the car that wants to change lane from left to right
LR gap_-^2	Gap on the target lane 2 behind the car that wants to change lane from left to right
LR gap_-^3	Gap on the target lane 3 behind the car that wants to change lane from left to right
LR gap_+	Gap on the target lane in front of the motorcycle that wants to change lane from left to right
LR gap_-	Gap on the target lane behind the motorcycle that wants to change lane from left to right
v_{LSL}	Velocity of the car or of the motorcycle on the LSL within a certain distance one looks ahead
v_{LMSL}	Velocity of the car or of the motorcycle on the LMSL within a certain distance one looks ahead
v_{RMSL}	Velocity of the car or of the motorcycle on the RMSL within a certain distance one looks ahead
v_{RSL}	Velocity of the car or of the motorcycle on the RSL within a certain distance one looks ahead
RL gap_+^1	Gap on the target lane 1 in front of the car that wants to change lane from right to left
RL gap_+^2	Gap on the target lane 2 in front of the car that wants to change lane from right to left
RL gap_+^3	Gap on the target lane 3 in front of the car that wants to change lane from right to left
RL gap_-^1	Gap on the target lane 1 behind the car that wants to change lane from right to left
RL gap_-^2	Gap on the target lane 2 behind the car that wants to change lane from right to left
RL gap_-^3	Gap on the target lane 3 behind the car that wants to change lane from right to left
RL gap_+	Gap on the target lane in front of the motorcycle that wants to change lane from right to left
RL gap_-	Gap on the target lane behind the motorcycle that wants to change lane from right to left

LMSL. The RL gap_+^1, RL gap_+^1, RL gap_-^1, and RL gap_-^2 values change correspondingly from left to right sublanes, and suitable values were considered for lane changing.

(1) For Car from RSL to RMSL. If $v_n^{(c)} \leq \text{RL gap}_+^1$, $v_n^{(c)} \leq \text{RL gap}_+^2$, $\text{RL gap}_-^1 \geq v_{\max}^{(c)}$, $\text{RL gap}_-^2 \geq v_{\max}^{(c)}$, $v_{\text{RSL}} \leq v_n^{(c)}$, and $v_{\text{RSL}} \leq v_{\text{RMSL}}$, then, car changes from RSL to RMSL.

(2) For Car from RMSL to LMSL. If $v_n^{(c)} \leq \text{RL gap}_+^1$, $v_n^{(c)} \leq \text{RL gap}_+^2$, $\text{RL gap}_-^1 \geq v_{\max}^{(c)}$, $\text{RL gap}_-^2 \geq v_{\max}^{(c)}$, $v_{\text{RMSL}} \leq v_n^{(c)}$, and $v_{\text{RMSL}} \leq v_{\text{LMSL}}$, then, car changes from RMSL to LMSL.

2.2.4. For Cars Changing Two Sublane Right to Left

(1) For Car from RSL to LMSL. If $v_n^{(c)} \leq \text{RLgap}_+^2$, $v_n^{(c)} \leq \text{RLgap}_+^3$, $\text{RLgap}_-^2 \geq v_{\max}^{(c)}$, $\text{RLgap}_-^3 \geq v_{\max}^{(c)}$, $v_{\text{RSL}} \leq v_n^{(c)}$ (if car) or $v_{\text{RMSL}} \leq v_n^{(c)}$ (if motorcycle), and $v_{\text{LMSL}} \leq v_{\text{LSL}}$ or $v_{\text{RSL}} \leq v_{\text{LSL}}$, then, car changes from RSL to LMSL.

2.2.5. For Motorcycles from Left to Right. Here, a motorcycle can change 3 different sublanes, LSL to LMSL, LMSL to RMSL, and RMSL to RSL. The LR gap_+ and LR gap_- values are calculated for all the sublane changes from left to right, and the corresponding values were used for the calculation.

(1) For Motorcycle from LSL to LMSL. If $v_n^{(m)} \leq \mathrm{LR\,gap_+}$, $\mathrm{LR\,gap_-} \geq v_{\max}^{(m)}$, $v_{\mathrm{LSL}} \leq v_n^{(m)}$, and $v_{\mathrm{LSL}} \leq v_{\mathrm{LMSL}}$, then, motorcycle changes from LSL to LMSL.

(2) For Motorcycle from LMSL to RMSL. If $v_n^{(m)} \leq \mathrm{LR\,gap_+}$, $\mathrm{LR\,gap_-} \geq v_{\max}^{(m)}$, $v_{\mathrm{LMSL}} \leq v_n^{(m)}$, and $v_{\mathrm{LMSL}} \leq v_{\mathrm{RMSL}}$, then, motorcycle changes from LMSL to RMSL.

(3) For Motorcycle from RMSL to RSL. If $v_n^{(m)} \leq \mathrm{LR_{gap_+}}$, $\mathrm{LR_{gap_-}} \geq v_{\max}^{(m)}$, $v_{\mathrm{RMSL}} \leq v_n^{(m)}$, and $v_{\mathrm{RMSL}} \leq v_{\mathrm{RSL}}$, then, motorcycle changes from RMSL to RSL.

2.2.6. For Motorcycles from Right to Left. Here, a motorcycle can change the lane from RSL to RMSL, RMSL to LMSL, and LMSL to LSL. The $\mathrm{RL\,gap_+}$ and $\mathrm{RL\,gap_-}$ values are calculated for all the sublane changes from left to right, and the corresponding values were used for the calculation.

(1) For Motorcycle from RSL to RMSL. If $v_n^{(m)} \leq \mathrm{RL\,gap_+}$, $\mathrm{RL\,gap_-} \geq v_{\max}^{(m)}$, $v_{\mathrm{RSL}} \leq v_n^{(m)}$, and $v_{\mathrm{RSL}} \leq v_{\mathrm{RMSL}}$, then, motorcycle changes from RSL to RMSL.

(2) For Motorcycle from RMSL to LMSL. If $v_n^{(m)} \leq \mathrm{RL\,gap_+}$, $\mathrm{RL\,gap_-} \geq v_{\max}^{(m)}$, $v_{\mathrm{RMSL}} \leq v_n^{(m)}$, and $v_{\mathrm{RMSL}} \leq v_{\mathrm{LMSL}}$, then, motorcycle changes from RSL to RMSL.

(3) For Motorcycle from LMSL to LSL. If $v_n^{(m)} \leq \mathrm{RL\,gap_+}$, $\mathrm{RL\,gap_-} \geq v_{\max}^{(m)}$, $v_{\mathrm{LMSL}} \leq v_n^{(m)}$, and $v_{\mathrm{LMSL}} \leq v_{\mathrm{LSL}}$, then, motorcycle changes from RSL to RMSL.

2.3. Step III: Deceleration. If $\mathrm{dist} < v_n^{(c)}$ then $v_n^{(c)} \rightarrow \min(v_n^{(c)}, \mathrm{dist})$ for car.

If $\mathrm{dist} < v_n^{(m)}$ then $v_n^m \rightarrow \min(v_n^{(m)}, \mathrm{dist})$ for motorcycle.

2.4. Step IV: Randomisation. If $v_n^{(c)} > 0$ then $v_n^{(c)} \rightarrow \max(v_n^{(c)} - 1, 0)$ with probability sp.

If $v_n^{(m)} > 0$ then $v_n^{(m)} \rightarrow \max(v_n^{(m)} - 1, 0)$ with probability sp.

2.5. Step V: Movement. $x_n^{(c)} \rightarrow x_n^{(c)} + v_n^{(c)}$ for car.

$x_n^{(m)} \rightarrow x_n^{(m)} + v_n^{(m)}$ for car.

3. Simulation and Discussion

For the simulation, a system with 6000 sites is considered with the boundary conditions. As discussed in Section 2, the length of each site is set to be 4.0 m and the width to be 1.25 m to 1.50 m. The maximum speed for the car $v_{\max}^{(c)}$ and motorcycle $v_{\max}^{(m)}$ is set to be 5 units. One iteration time steps is taken as 1 Sec. If we consider 5 units/time-steps, then, the maximum speed for car and motorcycle comes out to be $v_{\max}^{(c)} = v_{\max}^{(m)} = 72$ km/hr.

While starting the simulation, the cars are initially distributed randomly on the road with the given density $\rho^{(c)}$, and motorcycles are distributed with given density $\rho^{(m)}$. The simulation is done with 10000 time steps, and the average velocity (space mean speed) of the cars and motorcycles was obtained.

The speed, flow, and density for a traffic system is given by

$$Q = \rho v. \tag{3}$$

For mixed traffic flow

$$Q^t = Q^{(c)} + Q^{(m)} = \rho^{(c)} v^{(c)} + \rho^{(m)} v^{(m)}, \tag{4}$$

where $Q^{(c)}$ and $Q^{(m)}$ represent the average flow of the cars and motorcycles, respectively. All the values were obtained using simulation results.

3.1. Flow Behavior. Flow density relationship is one of the important factors which depict the traffic flow stream. The flow density variation is governed by the factors such as time and location. When there are no vehicles on the road, then, the density is zero, therefore, flow is also zero. When the number of vehicles starts increasing, the flow and density increase. Further increase in the vehicle creates the jam, called jamming density in which the flow will be zero. This is some density between zero density and jam density where there will be maximum flow.

Figure 2 represents the relation between the flow and density for different motorcycle densities. The car flow versus the car density is represented in Figure 2(a). The maximum flow of cars is more than the Na-Sch model for cars due to the lane changing, even with the presence of motorcycles. But, after motor cycle density crosses a certain limit, the car flow decreases, this is because of the presence of motorcycles which obstruct the car flow.

Second, the maximum car flow decreases with an increase in the motorcycle density $\rho^{(m)}$. The result further shows that the critical density $\rho_c^{(c)}$ at which the maximum car flow can occur will increase at the same time with the increase in the motorcycle density till $\rho^{(m)} = 0.2$. But, further increase in $\rho^{(m)}$ shows a decrease in the critical car density $(\rho_c^{(c)})$, which causes maximum car flow.\

Similarly, the relation between the total flow and total density for different motorcycle densities is given in Figure 2(b). The results represent the maximum total flow increase initially with the increase in the motorcycle density $\rho^{(m)}$; further increase in $\rho^{(m)}$ results in a decrease in the total flow. The critical total density $\rho^{(T)}$ at which the maximum flow occurs increases with an increase in the motorcycle density $\rho^{(m)}$.

In order to evaluate the motorcycle flow, the relation between the motorcycle flows with the car density is plotted in Figure 3(a). Similarly, the flow density relation of the Na-Sch model for a motorcycle is given in Figure 3(b). The critical motorcycle density for the Na-Sch model is $\rho_c^{(m)} = 0.15$. Figure 3(a) shows that, for a particular car density, the motorcycle flow $Q^{(m)}$ increases and reaches maximum flow $Q_{\max}^{(m)}$
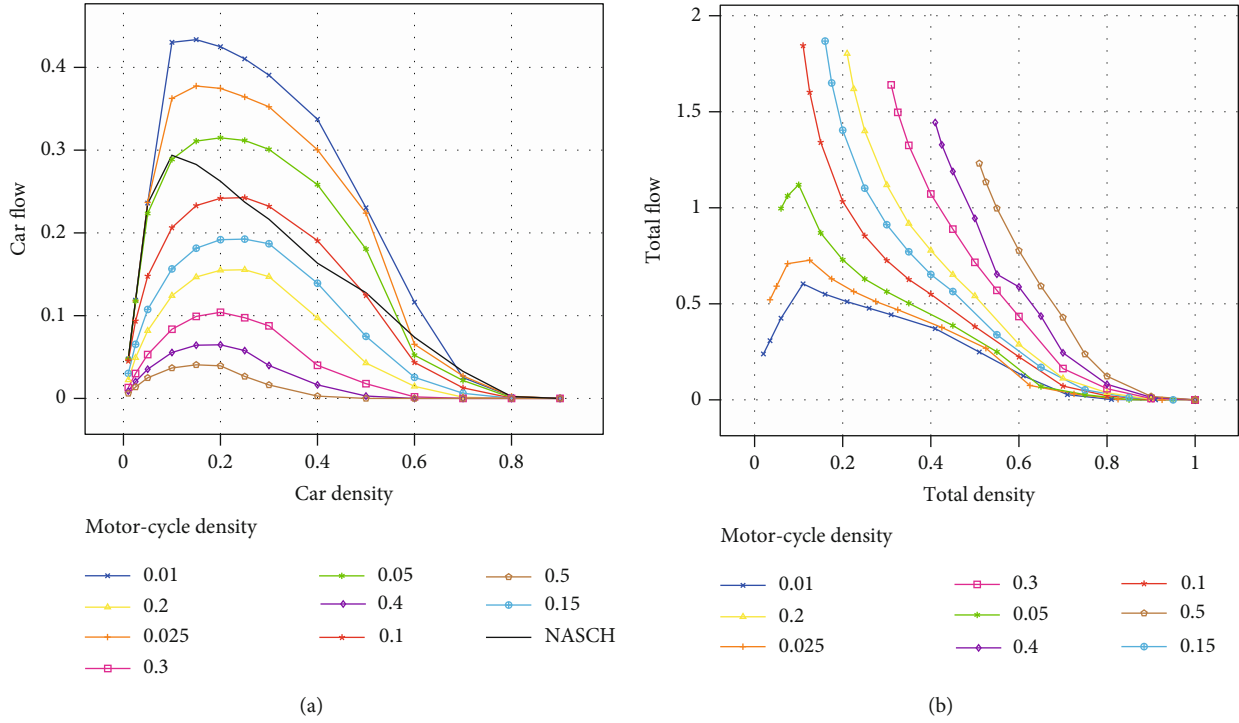
FIGURE 2: (a) Flow diagrams with sp = 0.25 and Ip = 0.25 for different motorcycle density. (b) Flow density diagrams with sp = 0.25 and Ip = 0.25 for different motorcycle density.
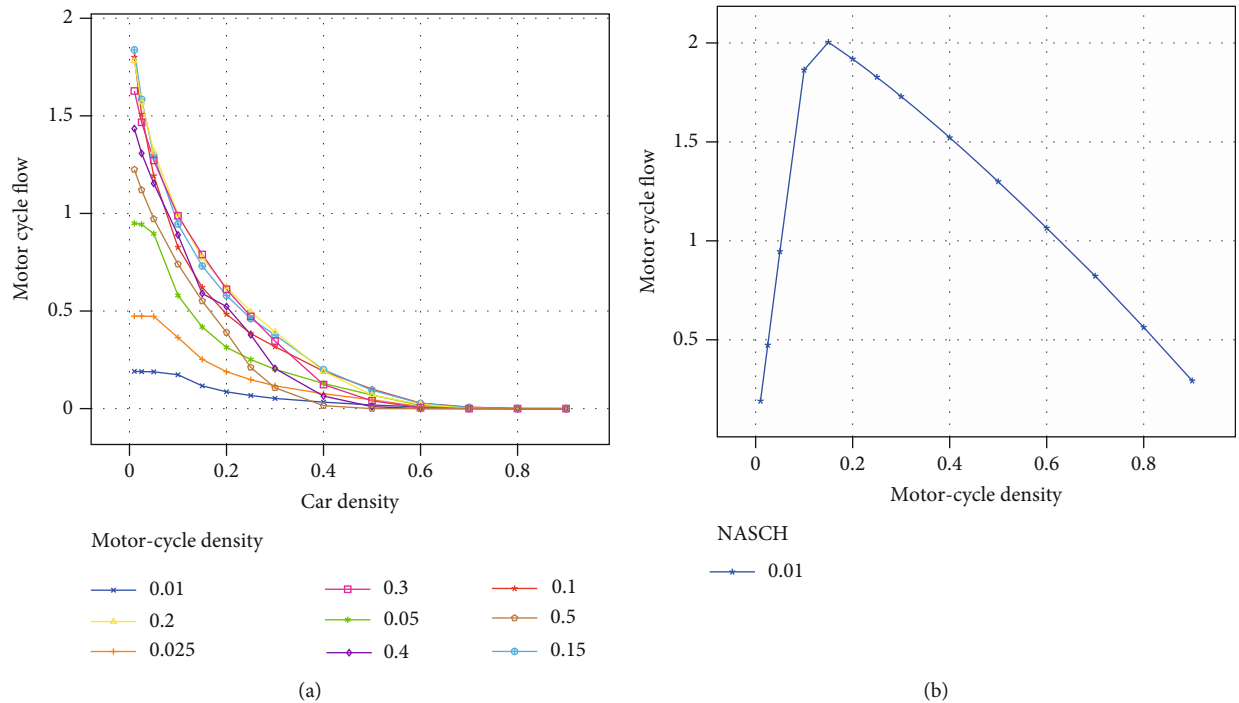

FIGURE 3: (a) Relation between the motorcycle flow and the car density with sp = 0.25 and Ip = 0.25 for different motorcycle densities. (b) Flow density relation of Na-Sch model for motorcycle.

with increases in the $\rho^{(m)}$ in the region $\rho_c^{(m)} = 0.15$. Furthermore, with the increase in $\rho^{(m)}$, the motorcycle flow $Q^{(m)}$ starts decreasing. The maximum motorcycle flow for the Na-Sch model is comparatively higher than the maximum motorcycle flow in presence of $Q_{\max}^{(m)}$. When the density of the car is small, in the region $\rho^{(m)} > \rho_c^{(m)}$, the flow $Q^{(m)}$ is more than
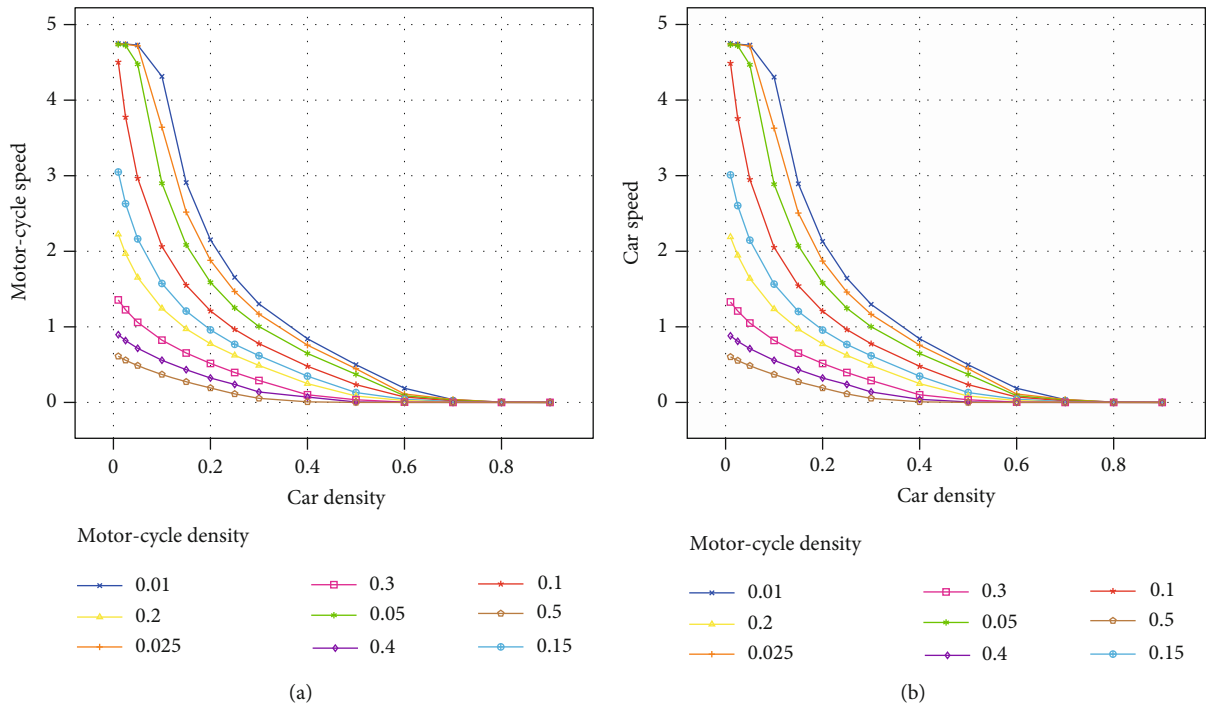
FIGURE 4: (a) Speed density diagrams with sp = 0.25 and Ip = 0.25 for different motorcycle densities. (b) Speed density diagrams for cars with sp = 0.25 and Ip = 0.25 for different motorcycle densities.
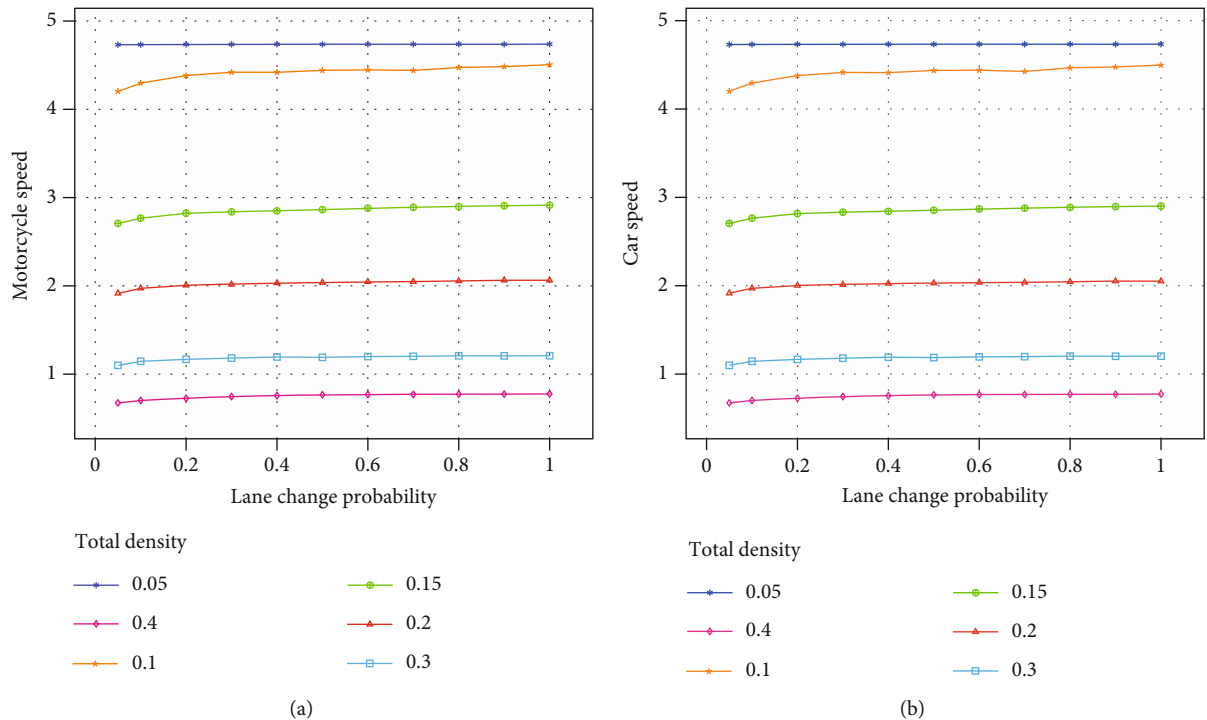

FIGURE 5: (a) Motorcycle speed V/s lane change probability diagrams with sp = 0.25 for different total densities. (b) Car speed V/s lane change probability diagram with sp = 0.25 for different total densities.

the flow in the Na-Sch model for motorcycles, and in the region $0 < \rho^{(m)} > \rho_c^{(m)}$, the flow is almost equal to motorcycle flow in the Na-Sch model. But when $\rho^{(m)}$ is larger, the flow increases due to the lane changing of motorcycles.

3.2. Effect of Lane Changing Behavior on Speed and Flow. The speed-density relation for the different motorcycle densities is represented in Figure 4. Both the motorcycle speed and the car speed decrease with the increase in the density. The
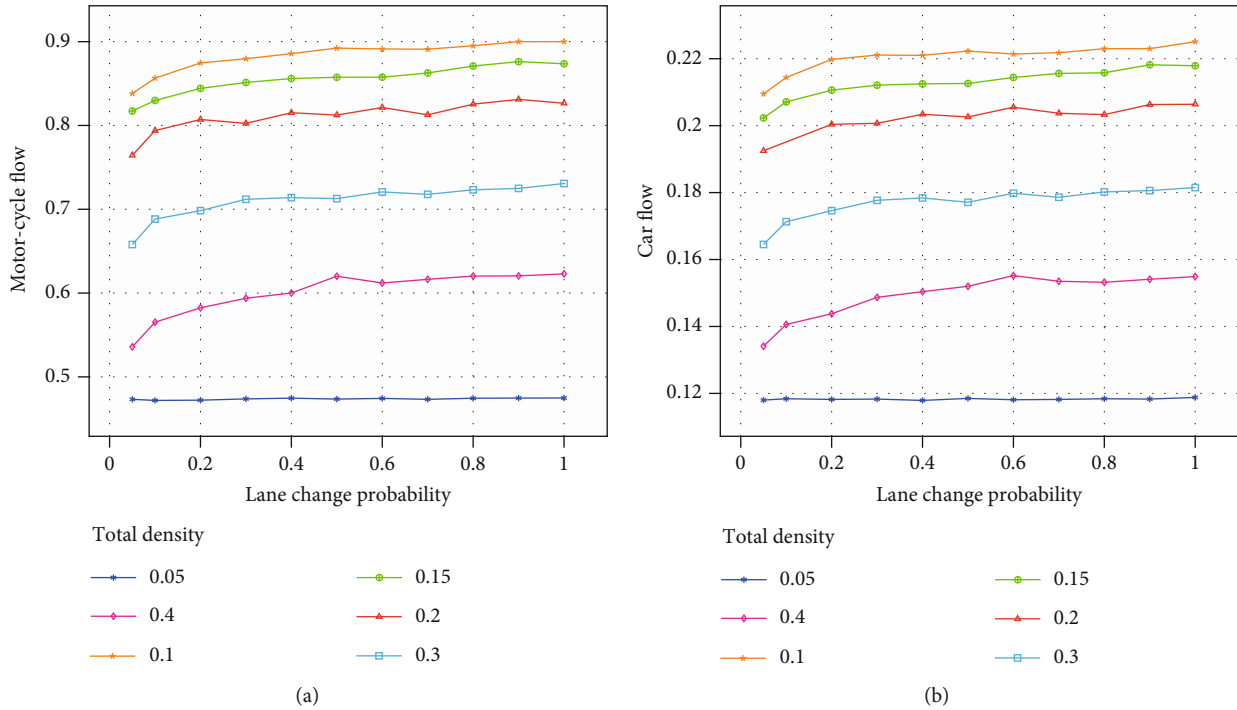
FIGURE 6: (a) Motorcycle flow v/s lane change probability diagram with sp = 0.25 for different total densities. (b) Car flow v/s lane change probability diagram with sp = 0.25 for different total densities.

diagram follows the standard pattern of the speed density graph. The maximum speed of the car and motorcycle occurs at a very lower density, i.e., when density is zero, the vehicle is moving at free-flow speed. For a particular motorcycle density, as the car density increases, the motorcycle speed decreases. Similarly, the car speed also decreases with the increase in the car density, i.e., when the density becomes jam density, the speed becomes zero.

In order to evaluate the effect of lane-changing behavior on vehicular speed, we investigate the relation between the lane-change probabilities with the speed. Lane-change probability is defined as the probability below which the lane-change occurs. Figure 5 shows the relation between the speed of the motorcycle and the car with the lane change probability. For a particular lane change probability, as the totaldensity increases, the speed of both cars and motorcycle decreases. One can see that as the lane changing probability increases, the speed increases initially and remains constant, and further increase in the lane change probability will not increase in speed. This behavior can be attributed to the fact that when the lane change probability is zero, the vehicle moves in the same lane without lane changing. But as lane change probability increases the speed of the vehicle increases, due to further increase in the lane change probability, each vehicle tries to obstruct other vehicles by moving aggressively in order to change the lane resulting in no increase in speed. But the interesting is that for lesser densities, the lane change probability has no effect on the speed of the car and motorcycle. This is because at lower densities, the number of vehicles is less, and each vehicle has enough space in front in order to accelerate

and maintain its speed, which further need not change the lane to maintain its speed.

A similar graph of flow versus the lane changing probability is plotted in Figure 6. The result shows that at a particular lane change probability, the flow rate increase for increase in the total density (till the total density of 0.1), and further increase in the density results in decrease in the total flow. Similarly for the particular density, the increase in the lane change probability results in an increase in the flow and remains constant, and further increase in the lane change probability has a very little effect on the flow rate. But at the lesser density, the lane change probability has no effect on flow rate.

4. Conclusions

This study extends the work of Lan et al. [19] and Meng et al. [21] in developing a CA model to simulate the mixed traffic comprising of cars and motorcycles. The analysis uses a finer cell system to analyse the different dimension of traffic with cars and motorcycles. In this study the most significant factor considered is the intermediate lane width, since most of the Indian roads have intermediate lane width . The position of vehicle at all possible location in the lane width is considered in this study and this is one of the important factors which was not yet investigated in the existing research. The study involves the effect of lane change probability on the flow and speed of the traffic stream. The simulation result reveals that as the lane change probability increases the speed and flow increase, but further increase in the lane change

probability has no effect on speed and flow. This is because due to the more aggressiveness of the drivers, the vehicle will obstruct themselves, resulting in no further increase in speed and flow.

Data Availability

No data were used to support this study. This paper present the results of a traffic simulation model and it does not contain any data. The main contribution in this paper includes the developed of the model and the simulation results.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

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