Traffic flow modelling using Cellular automata

Jay Goswami (201501037)* and Vishal Shingala (201501450)†
Dhirubhai Ambani Institute of Information & Communication Technology, Gandhinagar, Gujarat 382007, India
CS-302, Modeling and Simulation

In this course project we have implemented a model of vehicular traffic flow using cellular automata. We have implemented the Nagel-Schreckenberg Model for one lane, RNSL model for two lanes and DM model for three lanes. We have examined the influence on traffic flow due to slow vehicles and road blocks/accidents in a multi-lane system.

I. INTRODUCTION

Traffic of vehicles is a problem increasing day by day. Due to limited resource i.e. roads, and growing population, number of vehicles are increasing. And there is need for optimization of traffic flow for which modelling of traffic flow must be studied. One of the first realistic description of traffic on freeways using cellular automata (as opposed to the way of studying traffic with fluid dynamics model) was Nagel and Schreckenberg (NaSch model)[1], which is probabilistic one lane model with use of four rules. Although using NaSch, phenomena similar to ones encountered in real life traffic flow can be modelled, it is minimal in the sense that it consists of independent one lanes and all vehicles of one type and that gave rise to models with multi-lane traffic flow model. In multi-lane models, rules are introduced to define how vehicle changes lane. Two lane model (RNSL) based on NaSch model was introduced in 1995[2] and DM model which models three lane traffic was introduced in 2003[3]. All of these three model are modelled and simulated in this project and analysis of them are also included in this project.

II. MODEL

A. Nagel Schreckenberg Model (NaSch)

This model is one lane model which can be defined by one dimensional array of L sites with open boundary condition. Each site or cell can either contain vehicle or be empty. Each vehicle has some integer velocity associated to it ranging from 0 to v_{max}. On each update we follow four steps as given below.

1. Acceleration: If velocity of vehicle v is less than maximum velocity v_{max} and next vehicle from current vehicle is at distance more than $v + 1$ than speed of vehicle is increased by 1.

2. Slowing down (braking): If next vehicle is at distance less than v from current vehicle, than vehicle slows down with reduced speed of distance between them. (distance refers to number of empty cells between current to next vehicle.)

3. Randomness: Each vehicle's speed is decreased by one with probability of p_{brake}.

4. Car site update: Each vehicle moves v sites forward.

After all steps above are followed in order, we can get lane configuration at time $t + 1$ from t.

B. RNSL Model

RNSL model is dual lane model which consist of two parallel single lane model. It contains some additional rule including also all 4 rules of NaSch model. We also include lane changing rules for vehicles. Update of system in this model is done in following two steps.

1. See for lane changes under lane changing rule. If condition are met for lane change, vehicle is moved to lane next to current lane without going forward in new lane.

2. We update the system from time t to time $t + 1$ using same rules mentioned in NaSch model.

Lane change rules:
Suppose k is the position of the k^{th} site on lane j. Then let k_j is the site on the lane j, containing the nearest car to site k from backward. Let k_{+j} be site on lane j that contains the nearest car to site k from forward. And x_{i_j} represents the i^{th} position of the vehicle in lane j, then the following variables which helps in defining rules are defined as:

- $gap(i)_j = x_{i+1_j} - x_{i_j} - 1$, Empty cells between current vehicle and next vehicle in front on lane j

- $gap_o(i)_{jk} = (x_{i_j})_{+k} - x_{i_j} - 1$, Empty cells between site where you want to change lane and next vehicle in front on that lane k.

*Electronic address: 201501037@daiict.ac.in
†Electronic address: 201501450@daiict.ac.in

- $gap_{o,back}(i)_{jk} = x_{i_j} - (x_{i_j})_{-k} - 1$ Empty cells between site where you want to change lane and previous vehicle in rear on that lane k.

We define rules for lane change at each time t as below.

1. $gap(i)_j < l$
2. $gap_0(i)_{jk} < l_o$
3. $gap_{o,back}(i)_{jk} < l_{o,back}$
4. $rand() < p_{change}$
5. Vehicle changes the lane j to lane k placing in position i of the lane k.
6. The system is updated by applying the rules one lane model (NaSch) independently to each lane.

here l, l_o, and $l_{o,back}$ are the parameters which decide how far you look ahead on your lane, ahead on the other lane, or back on the other lane. Also to perform the lane change we associate probability p_{change} of a vehicle lane change.

For simulation purpose we take the values of the parameters as $l = min(v_i + 1; v_{i_{max}})$, $l_o = l$ and $l_{o,back} = v_{i_{max}}$.

C. DM Model

This model is three lane model similar to two lane model (RNSL). This model consider road as three lanes where each lane will be represented as 1D array of size L similar to NaSch model. Update rules of sites are same as in RNSL model. Additional to that we introduce some lane change rules as given below.

I. Incentive Criteria :

$v_{hope}(i) > gap(i)_j$; with $v_{hope} = min(v + 1; v_{max})$ This criterion is valid for whichever lane contains the considered vehicle.

II. Safety Criteria :

(a). If the i^{th} vehicle is in the lane $j = 1$ or $j = 3$ and are met following conditions:

1. $gap_o(i)_{j2} > gap(i)_j$,
2. $gap_{o,back}(i)_{j2} > v_{max}$,
3. $rand() < p_{change}$, with p_{change} the probability parameter lane change, then the vehicle changes from lane j to lane 2 placing in position i of the lane 2.

(b). If the i^{th} vehicle is in lane 2 and are met following conditions:

1. $gap_o(i)_{2j} > gap(i)_2$,
2. $gap_{o,back}(i)_{2j} > v_{max}$,
3. $rand()$ ¡ p_{change}, then the vehicle changes from lane 2 to lane j placing in position i of the lane j.

III. The system is updated by applying the rules One lane model (NaSch) independently to each lane.

III. RESULTS

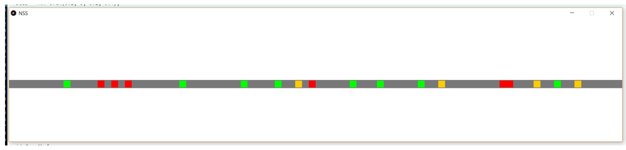

FIG. 1: Graphical simulation of One lane model (NaSch)

For analyzing result we define few parameters as given below
N = number of vehicles
L = number of cells in a single lane
$< v >$ = average velocity of all vehicles in one lane
Density, $\rho = \frac{N}{L}$
Flow, $\phi = \frac{1}{T}\frac{1}{L} < v >$ [2]

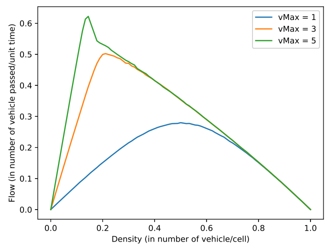

FIG. 2: For NaSch model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with different v_{max}. ($p_{brake} = 0.2$, $L = 900$ and total t = 15000 time steps)

For NaSch model, as observed from figure 2, flow initially increases with increase in density (ρ) as number of vehicles will increase but after a certain density (ρ) due to the sudden appearance of traffic jams i.e vehicles are much more than optimal conditions, flow starts decreasing. The optimal density for maximum flow can also be found as $\rho = \frac{1}{v_{max}+1}$ [5], i.e. for $v_{max} = 5$ is 0.167, $v_{max} = 3$ is 0.25 and for $v_{max} = 1$ is 0.5, which the graph satisfies.

As the value $p-brake$ is increased(i.e. car driver slows down car on a regular interval), it results in lesser flow i.e. peak value of flow and overall whole flow decreases, which can be seen from Fig. 3. The peak flow is also achieved at a lower density.

The single lane model (NaSch) is not capable of modelling realistic traffic because of a reason that in reality

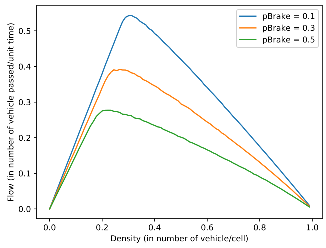

FIG. 3: For NaSch model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with different p_{brake}. ($v_max = 5$, $L = 900$ and total $t = 15000$ time steps)

there are different vehicles with different velocity. Introducing such different vehicle types in the single lane model results in grouping of slow vehicles being followed by faster ones and the average velocity reduced to the maximum velocity of the slowest vehicle.

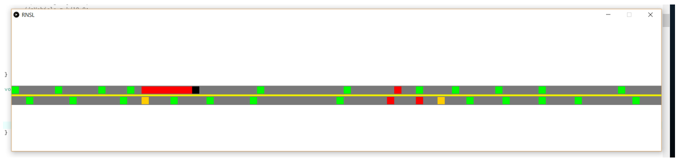

FIG. 4: Graphical simulation of two lane model (RNSL)

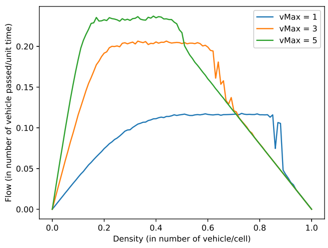

FIG. 5: For RNSL model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with different v_{max}. ($p_{brake} = 0.2$, $L = 10000$ and total $t = 5000$ time steps)

The RNSL model for two lane model shows similar behaviour with NaSch model which can be observed from figure 5. Initially flow increases with increase in density, but after enough increase in density flow becomes constant opposite to observed in NaSch model where after peak value it decreases. This constant flow with increase in density can be explained with lane change rules. As vehicle now can change lane, it increases average velocity compared to NaSch model. And at very high density (0.8), the flow decreases, as the lane change isn't possible in such high traffic.

Sometimes, an accident can happen, which can hamper the traffic flow. [6]. Thus, an attempt to simulate how accidents/road blocks influence the traffic flow, a single cell in the two lane model is blocked. The traffic flow is dampened due to the block, as can be seen in fig. 6. But still, although at a slower rate, the traffic still flows due to the lane changing rules.

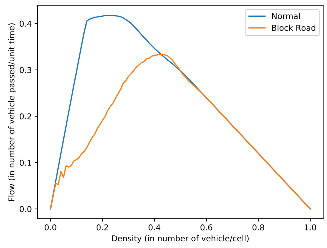

FIG. 6: For RNSL model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with one cell blocked in a lane. ($v_{max} = 5$, $p_{brake} = 0.2$, $L = 10000$ and total $t = 5000$ time steps)

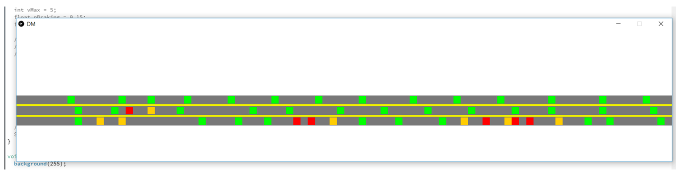

FIG. 7: Graphical simulation of three lane model (DM)

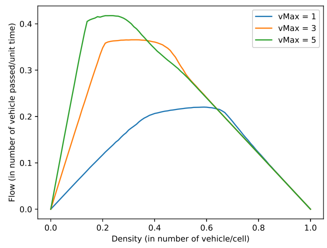

FIG. 8: For DM model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with different v_{max}. ($p_{brake} = 0.15$, $L = 13333$ and total $t = 5000$ time steps)

For DM Model for three lane, some similarities with NaSch model can be seen from figure 8 such as peak value is obtained with formula of ρ given in NaSch model. Also the peak value is maintained for a larger range of density than in NaSch model due to lane changes, which is similar to the result obtained for RNSL model.

Including asymmetric vehicles in system results in shift of optimal density depending on other vehicle's maximum velocity (v_{max}). Simulation result for DM model of two type of vehicles with $v_{max} = 2$ and $v_{max} = 5$ is given in figure 9. Here since the second type of vehicle has less maximum velocity, so it decreases resultant flow of

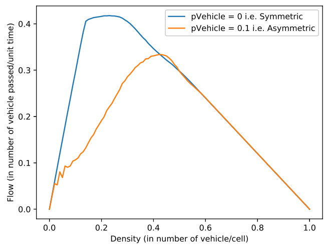

FIG. 9: For DM model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with vehicles of same type(symmetric) and vehicles of different type(asymmetric). ($v_{max} = 5$, $v_{max_2} = 2$, $p_{brake} = 0.15$, $L = 13333$ and total $t = 5000$ time steps)

system and peak value is achieved at higher density as resultant system will have less optimal flow and to achieve such flow higher density is needed.

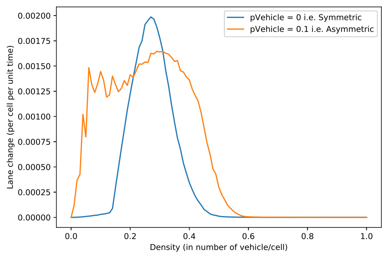

FIG. 10: For DM model, Lane changes (per unit cell per time step vs. density (in vehicles per site) from simulation results with vehicles of same type(symmetric) and vehicles of different type(asymmetric). ($v_{max} = 5$, $v_{max_2} = 2$, $p_{brake} = 0.15$, $L = 13333$ and total $t = 5000$ time steps)

When asymmetricity in speeds of vehicle is introduced, the number of lane changes starts increasing for a low value of density as compared to a symmetric one. This result is realistic, since if slower vehicles are present, faster vehicles will require changing lane to maintain their maximum velocity. The number of lane changes is significant for a large range of density in case of asymmetric one, as compared to the symmetric one.

For DM model, a block is introduced in the second lane. Including blockades in system results in decrease in peak (optimal) value of flow (shown in figure 11), very much similar to what was obtained in RNSL model. Comparing with RSNL model, since here the vehicle in blocked lane, has two lanes to choose from, the flow attains peak at a lower density than RNSL, but still the peak value is lower than non-blocked one, which is an impact on flow due to the blockage.

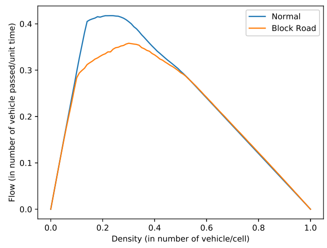

FIG. 11: For DM model, Traffic flow ϕ (in vehicles per time step vs. density (in vehicles per site) from simulation results with one cell blocked in a lane. ($v_{max} = 5$, $p_{brake} = 0.15$, $L = 13333$ and total $t = 5000$ time steps)

IV. CONCLUSIONS

In conclusion, we have studied different models of traffic flow using cellular automata. NaSch model consisting of one lane replicate phenomena of traffic in real world but today single lanes are almost distinct as multi lane highways have been built. RSNL model have two lane configuration with allowed lane changes of vehicle, but it still doesn't consider the fact that different vehicles have different maximum speed. Similarly DM model consisting three lanes allows lane changes but has different set of rules which matches with real world decision making of driver to change lane, and also assymetric vehicle speed. Analyzing the results obtained for different model, the density (ρ) of vehicles on road can be suggested such that flow (ϕ) of vehicles is maximized. Also during blockade or accident, traffic flow can be minimized with suggested density of vehicles on road and maximum velocity to prevent a jam.

[1] Nagel, Kai, and Michael Schreckenberg, *A cellular automaton model for freeway traffic*, Journal de physique I 2.12 (1992).

[2] Rickert Marcus, Kai Nagel, Michael Schreckenberg, and Andreas Latour, *Two lane traffic simulations using cellular automata*, Physica A: Statistical Mechanics and its Applications 231, no. 4 (1996).

[3] Daoudia, A. Karim, and Najem Moussa, *Numerical simulations of a three-lane traffic model using cellular automata*, Chinese journal of physics 41, no. 6 (2003).

[4] Luna-Benoso, B., J. C. Martinez-Perales, and R. Flores-Carapia, *Modeling traffic flow for two and three lanes through cellular automata*, In International Mathematical Forum, vol. 8, no. 22(2013).

[5] Nagel Schreckenberg Model(NaSch)- Wikipedia, `https://en.wikipedia.org/wiki/NagelSchreckenberg_model`

[6] Tavares, L. D., D. A. G. Vieira, R. R. Saldanha, and W. M. Caminhas, *Simulating car accidents with Cellular Automata traffic flow model*, de Oliveira, PP und Kari, J., Herausgeber, AUTOMATA (2009).