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Simulation of Traffic Flow in Presence of Traffic Light using Cellular Automata

KEYWORDS: Traffic noise, traffic light, cellular automata

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ABSTRACT *Traffic lights are one of the most powerful tools for urban traffic control available to city authorities. Their correct installation can improve both traffic flow and the safety of all road users. To move traffic safely and efficiently with minimum delay is an interesting and challenging field of interactions between mathematics and engineering sciences. TCA models have been extensively used to investigate traffic flow in many aspects and corresponding computations and simulations are rather convenient and effective.*

1. Introduction
Biham et al. [1] proposed a two-dimensional CA model (BML) for urban traffic, in which vehicles only hop from an intersection to another adjacent one is proposed. Jiang and Wu [9] used speed gradient model (SG model) for simulation. Chung and Hui [6] presented a two-dimensional TCA model to simulate a traffic jam due to faulty traffic lights. A microscopic simulation of traffic flow which takes into account the turning of vehicles at signalized intersections is done by Jin et al [11]. Taking an idea of BML model for city traffic [1] and Nasch model [15] of highway traffic, Chowdhury and Schadschneider [5] discussed a phase transition from the free-flowing dynamical phase to the completely jammed phase at a vehicular density which depends upon the time periods at the synchronized signals and the separation between them . Brockfield et al. [3] have studied impact of global traffic light control strategy by optimizing traffic light in two-dimensional CA model for city traffic. Sasaki and Nagatani [17] compared three different traffic light control strategies: simple synchronized, green-wave and random switching strategies on a single-lane roadway by using optimal velocity model. Huang and Huang [8] examined the benefits of traffic lights synchronization in TCA model and concluded that green light wave solution can be realized for unsaturated traffic flow. He et al. compared three different type of traffic light strategies via TCA model with anticipation [7]. Jiang and Wu [9] proposed a new stopped time dependent randomization TCA model and explained the dependence of saturated-flow on cycle-time. Neumann and Wagner [16] investigated TCA model with open boundaries on the basis of behaviour of moving block and standing block of vehicles in front of traffic lights observed via simulation. Varas et al. [19] studied mean velocity near resonant condition of city traffic by considering the synchronized and green-wave strategies. Nagatani [14] presented a deterministic TCA model which is described by simple difference equations rather than a set of update rules for vehicular traffic controlled by traffic light. Lure [13] used a Quasi linear differential equation of the first order for traffic flow density as a one-dimensional traffic flow model in the presence of two traffic lights. In the present paper velocity-dependent acceleration rate TCA model is investigated in presence of single and two-traffic lights control strategies. Two different type of traffic light control strategies: synchronized and green-wave are compared.

2. Single lane TCA model in presence of traffic light
The Nasch model [15] for single-lane in presence of traffic light on a highway is given by:

Acceleration Rule:

$$v_i^{(t)} = \min\left(v_i^{(t)}+1, V_{max}\right) \qquad (1)$$

Braking Rule (a): If the traffic light is red in front of i^{th} vehicle

$$v_i^{(t)} = \min\left(v_i^{(t)}, x_{i+1}^t - x_i^t - 1, x_S - x_i^t - 1\right) \qquad (2)$$

Braking Rule (b): If the traffic light is green in front of i^{th} vehicle

If the next two cells directly behind the traffic light are occupied

$$v_i^{(t)} = \min\left(v_i^{(t)}, x_{i+1}^t - x_i^t - 1, x_S - x_i^t - 1\right)$$

otherwise

$$v_i^{(t)} = \min\left(v_i^{(t)}, x_{i+1}^t - x_i^t - 1\right) \qquad (3)$$

Randomization Rule:

$$v_i^{(t+\delta t)} = \max\left(v_i^{(t)} - 1, 0\right) \qquad (4)$$

Forward Movement Rule:

$$x_i^{(t+\delta t)} = x_i^t + v_i^{(t+\delta t)} \qquad (5)$$

Where x_s the position of traffic light is, $x_{i+1}^t - x_i^t - 1$ is the number of empty cells in front of i^{th} vehicle and $x_s^t - x_i^t - 1$ is the number of cells between i^{th} vehicle and traffic light ahead at time t.

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3. Velocity dependent acceleration rate TCA model for signalized intersection

In this work a velocity-dependent acceleration rate TCA model is adopted. Mathematically this is given as:

Accelerati on Rule :

$$v_i^{(t)} = \min\ (v_i^{(t)} + a,\ V_{max}) \qquad (6)$$

Braking Rule (a) : If the traffic light is red in front of ith vehicle

$$v_i^{(t)} = \min(v_i^{(t)}, x_{i+1}^t - x_i^t - sz, x_s^t - x_i^t - sz) \qquad (7)$$

Braking Rule (b) : If the traffic light is green in front of ith vehicle

If the sz or more than sz number of cells directly behind the traffic light are empty

$$v_i^{(t)} = \min(v_i^{(t)}, x_{i+1}^t - x_i^t - sz)$$

otherwise

$$v_i^{(t)} = \min(v_i^{(t)}, x_{i+1}^t - x_i^t - sz, x_s - x_i^t - sz) \qquad (8)$$

Randomizat ion Rule :

$$v_i^{(t+\delta t)} = \max\ (v_i^{(t)} - 1, 0) \qquad (9)$$

Forward Movement Rule :

$$x_i^{(t+\delta t)} = x_i^t + v_i^{(t+\delta t)} \qquad (10)$$

where *sz* is the size of vehicle in term of cells whether it is light or heavy vehicle. a is acceleration rate.

4. Numerical Simulation

The simulation involves a *L*=10 *km* link, which has a junction at location 5 *km* for single traffic light and two junctions located at 3.25 *km* and 6.5 *km* for two traffic lights. The numerical simulation is carried out according to four rules on a closed track of 20,000 cells. The periodic boundary conditions are applied. N is the total number of vehicles distributed on the simulated road section. The computational formulae used in numerical simulation are given as follows:

$$\rho = \frac{N_1}{L} \qquad (11)$$

$$Q = \frac{1}{T}\sum_{t=1}^{t=T} m_d(t) \qquad (12)$$

Where N_1 is the total number of cells occupied by N vehicles.

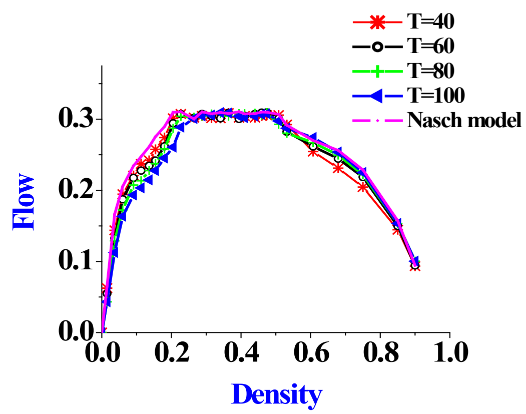

Figure 1: Relationship between flow and density of VDAR TCA in single traffic light.

5. Single lane traffic light situation

In this section a homogeneous highway with a length of *L*=km , having only one traffic light is considered. For simplicity, yellow light is not considered. The traffic lights are chosen to switch simultaneously after a fixed time period $T_c/2$. Time T_c is called the cycle-time of the traffic light.

First flow-density diagram of traffic flow induced by single traffic light is investigated. Figure 1 shows the graph of flow against density for different cycle-times in the range of 40-100 s with L fixed at 5 *km*. Initially flow increases with the density, when the density is higher than the first critical density (ñ > 0.18), flow saturates at the constant value. When the density increases furthermore and is higher than the second critical density (ñ > 0.5), the flow decreases with increasing density. The saturated-flow does not dependupon cycle-time. Solid line shows the plot for Nasch model, which differs from velocity-dependent acceleration rate TCA model in free-flow branch only. Saturated branch and congested branches are same for both models. This is due to that for Nasch model, the maximum speed limit is higher than that of present velocity-dependent acceleration rate TCA model.

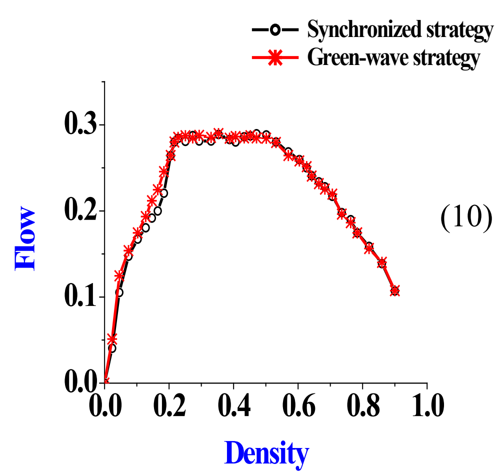

Figure 2: Relationship between flow and density of VDAR TCA model for two different type strategies

6. Synchronized traffic light situation

Figure 2 shows the comparison between two traffic light strategies at time-cycle T = 100. In low density region capacity-flow in the green-wave strategy is slightly higher than that in synchronized strategy. Saturated-flow and flow in high density region are almost same for two strategies. Therefore the green-wave strategy is better strategy than synchronized in low density region.

7. Conclusion

In this paper, the traffic flow situations controlled by traffic lights have investigated on a single-lane road by using velocity-dependent acceleration rate. It is found that dynamical transition to the flow saturation occurs when density is higher than the critical density ($\tilde{n} > 0.18$).

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