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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 11 (3): 388-391, 2012
ISSN 1812-5638 / DOI: 10.3923/itj.2012.388.391

Influence of Different Management Measures on Traffic Bottleneck Induced by the Reduction of Lanes

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Abstract: Two traffic cellular automata models corresponding to two different traffic management measures around the merging point of lane reduction bottleneck are proposed. One is the control scheme of first-arrive and first-in, the other is the periodic control scheme. The numerical simulations show that the consideration of different traffic measures could lead to the variation of the bottleneck capacity against the length of section B. And increasing signal period is helpful for improving the bottleneck capacity under Scheme 2. Moreover, the phenomenon of density inversion caused by the bottleneck may disappear under some traffic control regulations.

Key words: Traffic flow, lane reduction, cellular automata, management measures

INTRODUCTION

In the last decades, traffic dynamics has attracted much attention from physicists and mathematicians. There are a lot of models for traffic flow proposed thus far, from various viewpoints, such as macroscopic and microscopic, differential equations and cellular automata, deterministic and probabilistic, etc. (Chowdhury *et al*., 2000). Among these traffic models, the Cellular Automata (CA) model achieves a remarkable success although it is conceptually simpler compared with other dynamical approaches. The most famous one is NaSch model (Nagel and Schreckenberg, 1992). Later, various generalizations and extensions of the NaSch model have been proposed to simulate traffic flow, such as VDR model, TT model, CD model and so on (Chowdhury *et al*., 2000).

Lane reduction bottleneck, is common in road system. Near the merging point, drivers show obvious behaviors such as the aggressive lane change and lane squeeze, which affects the capacity seriously. Moreover, unreasonable traffic management measures have also magnified the adverse effects of bottleneck. Jia *et al*. (2003) investigated the traffic behaviors upstream of reduction bottleneck . Xue *et al*. (2010) studied two-lane traffic flow with partial reduction. Sheng *et al*. (2010) proposed a new CA model to study the temporary bottleneck induced by a special accident. However, the above research are mostly focused on the phase transition and the influence of this bottleneck on traffic flow. In this paper, using CA model, we aim to exploring the influence of different measures on traffic flux.

MODEL

As shown in Fig. 1, the road is divided into three sections: sections A, B and C. In the downstream of the merging point M (section C), the two-lane road merges into single-lane road. Thus, single-lane NaSch model is used in section C.

In sections A and B, vehicles can change lane, so the update step is usually divided into two sub-steps: in the first sub-step, cars may change lanes in parallel according to lane-changing rules and in the second sub-step, the two lanes are considered as independent single-lane NaSch models.

In section A, vehicles are not influenced by section C, consequently, they change lanes according to a symmetric rule (Chowdhury *et al*., 1997). if the following condition is satisfied:

$$d_n < \min(v_n+1, v_{max1}) \text{ and } d_{n,other} > d_n \text{ and } d_{n,back} > v_{max1} \text{ and rand}() < p_c. \quad (1)$$

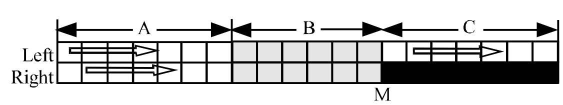

Fig. 1: Schematic illustration of the road

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Here $d_n = x_{n+1} - x_n$ is the gap of the vehicle n; $d_{n,\,other}$, $d_{n,\,back}$ denote the number of free cells between the nth car and its two neighbor cars on the other lane at time t, respectively; p_c is the probability of changing lane; v_{maxi} is the maximum velocity in section A, which is the same as of section C.

Section B is near the merging point M, it is usually deceleration zone and drivers' behaviors are different from that in other sections. One is the control scheme of first-arrive and first-in (called Scheme 1), namely, those vehicles on both lanes which first arrive at the merging point enter the reduction road first; the other is the periodic control scheme (called Scheme 2), i.e., supposing there is a signal light at the merging point, when the light is green, vehicles on left lane can enter, while the light red, vehicles on right lane can do. We also assume that there is no randomization deceleration, for drivers do not except to be hindered here and tend to move forward. Under Scheme 1, if condition

$$d_n < \min(v_n + 1, v_{max2}) \text{ and } d_{n,\,other} > d_n \text{ and } d_{\square,\,back} > 2 \quad (2)$$

is met, the car n on the left lane will change to right lane. If condition

$$d_n < \min(v_n + 1, v_{max2}) \text{ and } d_{n,\,other} > d_n \text{ and } d_{\square,\,back} > 2 \quad (3)$$

is met, the car n on the right lane will change to left lane. v_{max2} is the maximum velocity in section B. Under Scheme 2, the changing rules are symmetric, and here we still adopt the Eq. 3.

The boundary conditions are adopted as follows. On the left of the road system, if the hindmost vehicle position $x_{hindmost} > v_{max1}$, a car with velocity v_{max1} is injected with probability p_{in} at the cell min [$x_{hindmost} - v_{max1}$, v_{max1}]. On the right of the road system, if the most leading vehicle position $x_{leading} > L$ (L is the length of road), it moves without any hindrance.

SIMULATIONS AND DISCUSSION

In the simulations, section C is divided into ($200\times v_{max1}$) cells, section B into L_B cells and section A into ($200\times v_{max1} - L_B$) cells. Each cell corresponds to 7.5 m and a vehicle has a length of one cell. One time step corresponds to 1s. The parameters $v_{max1} = 5$, $v_{max2} = 3$, $p = 0.3$, $p_c = 0.5$ are selected, here p is probability of randomization deceleration. Each performance period is 1.2×10^4 time steps, and the first 10^4 time steps are discarded to let the transient time die out.

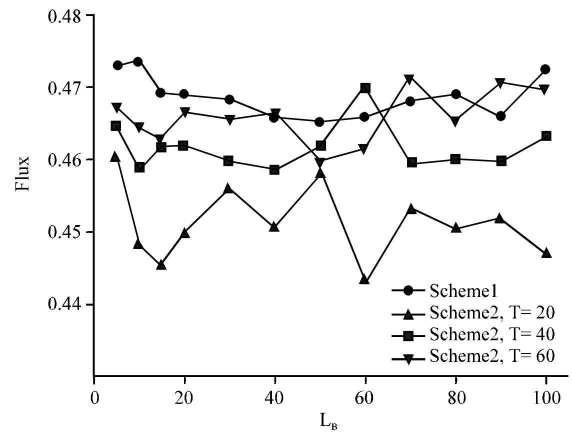

Fig. 2: The flux against the length of section B with $p_{in} = 0.3$

Figure 2 gives the flux of section C against the length of section B in the case of $p_{in} = 0.3$. Note that as $p_{in} > 0.24$, the flux remains a constant with respect to p_{in}, so the flux in Fig. 2 is also the capacity of bottleneck. Different from those in condition 3 where the capacity of bottleneck is independent on L_B, considering different traffic measures leads to the variation of the capacity of bottleneck against L_B. As L_B is small, the flux under Scheme 1 is highest. As for Scheme 2, with the increase of signal period T, flux also increases in view of the overall situation. This reflects when L_B is comparatively large, vehicles move orderly with the signal, which, to some extent, reduces the frequent aggressive lane change and lane squeeze, and thus the flux has been improved.

The density distribution as $p_{in} = 0.3$ for Scheme 1 is shown in Fig. 3. One can see that p_l is always equal to p_r in this case since vehicles on both lanes which first arrive at the merging point enter the reduction road first, it is needless to move on a specific lane. With the increase of L_B, a lot of vehicles move into this deceleration zone, and thus the density increases evidently. As $L_B = 50$, the density is close 0.8, much higher than that of $L_B = 5$.

Next, we investigate the influence of the signal period T on density distribution at the fixed $p_{in} = 0.3$ and $L_B = 20$ (Fig. 4). In contrast to p_r, p_l first slightly decreases and then increase as approaching M and is always much smaller than p_r. In addition, the density difference between p_l and p_r first increases and then decreases with the increase of T. In section C, p_l tends to stabilize at an approximately constant value.

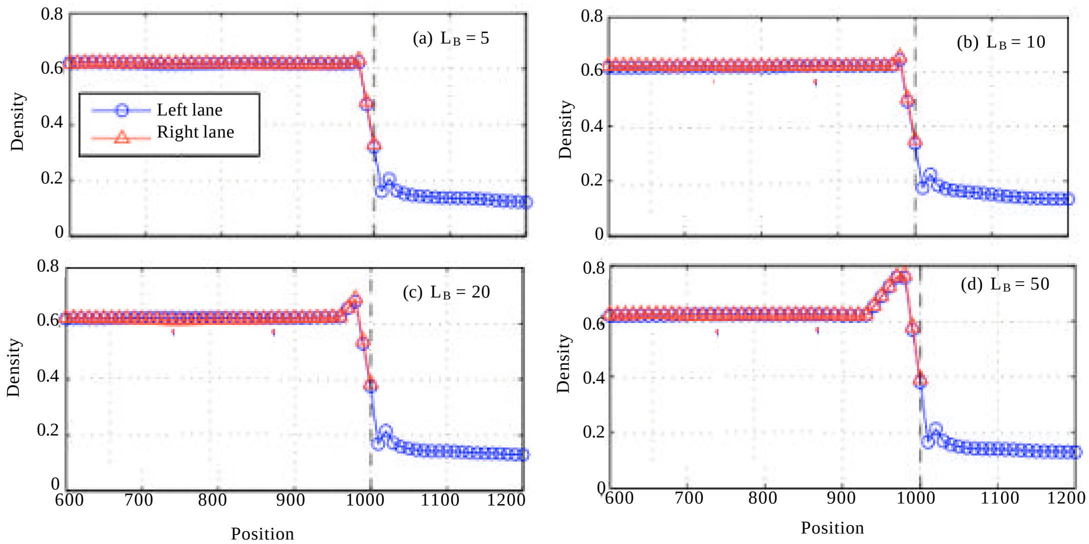

Fig. 3: Density distribution near M under different L_B with p_{in} = 0.3 for Scheme 1

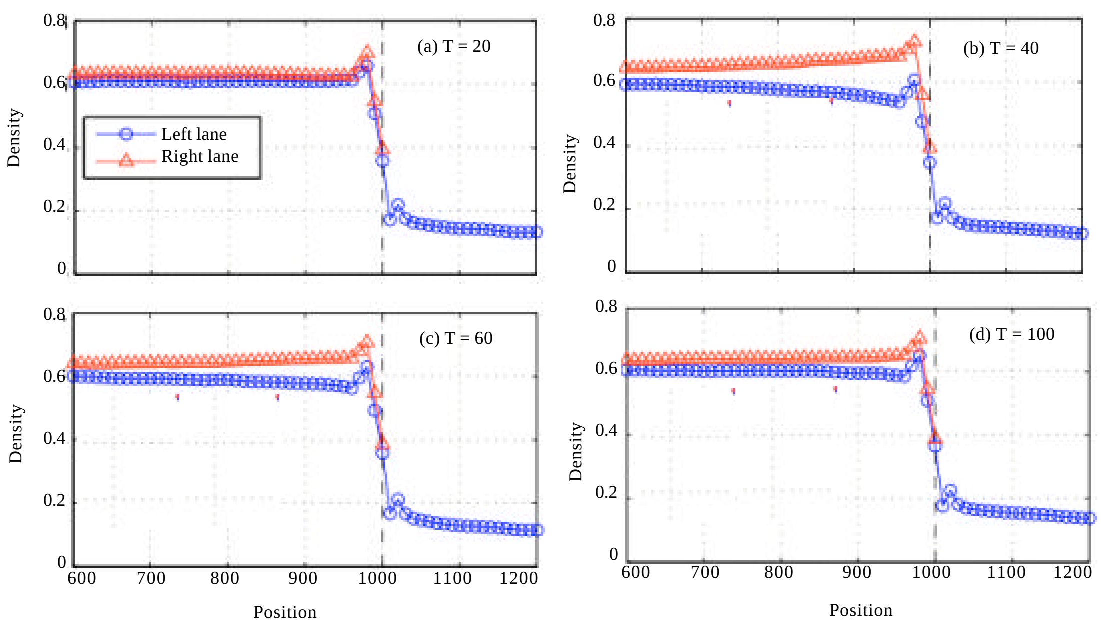

Fig. 4: Density distribution near M under different T with P_{in} = 0.3, L_B = 20 for Scheme 2

CONCLUSION

Our aim is to explore the influence of different management measures on bottleneck flux. To do so, we have proposed the first-arrive and first-in and the periodic control schemes. The numerical results show: (1) when the different traffic measures are considered, the capacity of bottleneck will vary against L_B; (2) to some extent, increasing period T is helpful for improving the bottleneck capacity under Scheme 2. The comparison of our simulation results with those in condition 3 enlightens us to obtain that the phenomenon of density inversion caused by the bottleneck may disappear due to the traffic regulations.

ACKNOWLEDGMENTS

This work was financially supported by the National Natural Science Foundation of China (10902076, 60904068, 10962002 and 11047003), the Top Young Academic Leaders of Higher Learning Institutions of Shanxi, the National Natural Science Foundation of Shanxi Province (2010011004), the National Natural Science Foundation of Zhejiang Province (Y6110502) and the Science Research Foundation for Doctors of Taiyuan University of Science and Technology (20082017).

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