Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Analysis of traffic congestion induced by the work zone[☆]

L. Fei, H.B. Zhu [*]

Faculty of Architectural, Civil Engineering and Environment, Ningbo University, Ningbo 315211, China

HIGHLIGHTS

- A meticulous two-lane cellular automaton traffic model is proposed.
- The difference of accelerations between moving state and starting state is considered.
- The vehicles' merging behavior in construction area is analyzed.
- The appropriate merging length and the speed limit value are recommended.

ARTICLE INFO

Article history:
Received 17 November 2015
Received in revised form 2 January 2016
Available online xxxx

Keywords:
Traffic flow
Work zone
CA model
Motion refinement
Traffic management measure

ABSTRACT

Based on the cellular automata model, a meticulous two-lane cellular automata model is proposed, in which the driving behavior difference and the difference of vehicles' accelerations between the moving state and the starting state are taken into account. Furthermore the vehicles' motion is refined by using the small cell of one meter long. Then accompanied by coming up with a traffic management measure, a two-lane highway traffic model containing a work zone is presented, in which the road is divided into normal area, merging area and work zone. The vehicles in different areas move forward according to different lane changing rules and position updating rules. After simulation it is found that when the density is small the cluster length in front of the work zone increases with the decrease of the merging probability. Then the suitable merging length and the appropriate speed limit value are recommended. The simulation result in the form of the speed–flow diagram is in good agreement with the empirical data. It indicates that the presented model is efficient and can partially reflect the real traffic. The results may be meaningful for traffic optimization and road construction management.

1. Introduction

The presence of work zone in two-lane or multi-lane highway could induce traffic jam and even traffic accidents. Then it is necessary to investigate the traffic properties when the road is in construction. The microscopic traffic simulation is one of the most efficient methods to analyze the traffic characteristics [1–10]. And the cellular automata (CA) models have been widely employed for traffic simulation, among which the NaSch model is one of the most famous CA models [1]. It is proposed by Nagel and Schreckenberg in 1992 dealing with single-lane traffic flow, which can reproduce some actual traffic phenomena, such as the spontaneous jams and the stop-and-go waves in traffic.

In order to simulate the actual traffic, many two-lane and multi-lane traffic models were proposed. Chowdhury et al. proposed the STCA model (Symmetric Two-lane Cellular Automata) and the ATCA model (Asymmetric Two-lane Cellular

☆ National Natural Science Foundation of China (Grant No. 10532060).
* Corresponding author.
E-mail address: zhuhuibing@nbu.edu.cn (H.B. Zhu).

http://dx.doi.org/10.1016/j.physa.2016.01.036
0378-4371/© 2016 Published by Elsevier B.V.

Automata) that are applied in many simulations [2]. Jia et al. put forward a realistic two-lane cellular automaton traffic model by considering the aggressive lane-changing behavior of fast vehicles and revealed the reason of ping-pang lane-changing Q4 behavior [3]. Knospe et al. proposed a comfortable driving model containing the brake lights and the expected speed, and the expected effect was introduced [4]. Zhu et al. presented the R-STCA model by considering the driving behavioral difference and the dynamic headway, and the phenomenon of the high speed car-following was indicated [5]. Tang et al. set up a multilane traffic flow model accounting for lane width, lane-changing and the number of lanes [6]. All these models are the foundation of the traffic modeling containing the work zone.

By now many traffic models have taken into account the difference of vehicles' behavior. For example, Tang et al. developed a new fundamental diagram theory based on the drivers' individual difference of their perception ability [11]. In addition, Tang et al. proposed an extended car-following model to study the influences of the driver's bounded rationality on his/her micro driving behavior, the fuel consumption and emissions [12]. Nevertheless all these models seldom consider the fact that the vehicles' maximum acceleration moving in a high gear state is different from that moving in a low gear state [13]. Otherwise these models can describe the traffic operation more meticulously.

Besides, the formation and the propagation of traffic jams induced by various traffic bottlenecks, i.e., on- and off-ramps, car accidents, toll stations, lane closing, etc., have been studied over years [14–17]. However the bottleneck in the form of the work zone has some unique features, and has become a research hotspot. Kim et al. systematically revealed the influence factors that related to the highway work zone [18]. Weng et al. proposed a work zone capacity model [19], and also proposed an improved CA model with a fine cell size to estimate the traffic delay occurred in the work zone [20].

In fact, the study of the vehicles' merging behavior in work zone is atmost importance in realizing the mechanics of traffic flow. In the past several decades, various models have been proposed to determine the merging distance [21–23]. Recently, Weng et al. investigate the speed–flow relationship and determine the desired merging location and the merging probability in merging area [24]. These models are useful for merging lanes designing. But all of them seem to isolate the merging behavior studying from the realistic traffic management measures. In other words, it will be more meaningful to study the required merging distance incorporating a certain traffic management measure. And then the optimal measurement for easing traffic congestion can be obtained after the underlying dynamics of traffic are investigated.

For all the above motivations, we propose a meticulous two-lane cellular automaton model, in which the difference of vehicles' accelerations is considered and the one-meter long cell length is adopted. Then a two-lane highway traffic model with a work zone is presented. The nonlinear characteristics of the traffic flow under the traffic management measures are analyzed. The appropriate merging length in front of the work zone and the speed limit value are recommended. The results may provide some theoretical reference for traffic optimizing.

The paper is organized as follows. The description of a modified two-lane traffic model with a work zone is presented in Section 2. In Section 3, simulation results in the forms of fundamental diagrams, the spatial–temporal profiles and the diagrams of the lane-changing rate are presented, and the underlying mechanism of traffic congestion is analyzed. Finally, concluding remarks and a summary of findings are contained in Section 4.

2. Outline of the model

2.1. Introduction of R-STCA model

Based on the STCA model proposed by Chowdhury et al. [2], a series of pioneering simulation researches of traffic flow have been carried out and some achievements are obtained. But the lane changing rules of the model are relatively conservative. It seems that the safety of vehicles is excessively emphasized, and the dynamic variation of the headway is neglected. In view of this shortage, Zhu et al. modified the STCA model by taking into account the driving behavioral difference and the dynamic headway, and named the R-STCA model [5]. Through numerical simulation and theoretical analysis, it is proved that the R-STCA model is more reasonable and more realistic.

In the R-STCA model, it is assumed that there are two types of vehicles in two-lane traffic, which move along one direction characterized by two different values of $v_{\max}$, i.e., $v^f_{\max}$ and $v^s_{\max}$, corresponding to the fast and slow vehicles respectively. In addition, drivers are divided up into radical drivers and cautious drivers. The former usually have radical characteristic and skilled driving ability and also drive fast vehicles, while the latter always drive vehicles carefully. The difference of drivers' personality is reflected in the vehicle position updating rules and the lane changing rules. That is to say, vehicles driven by different types of drivers move forward obeying different position updating rules and lane changing rules.

At first, let us introduce the updating rules in the R-STCA model. Actually they are the same as those in the DHD model [25], in which vehicles driven by two types of drivers move forward according to different updating rules. In brief, the cautious drivers move forward according to the updating rules of the NaSch model, while the radical drivers are supposed to be affected by the movement of the preceding vehicle. The updating rule of the preceding vehicle is expressed as follows,

$$v^e_{n+1} = \max(\min(v^e_{n+1} + 1, v_{\max(n+1)}, d_{n+1}) - 1, 0) \tag{1}$$

where, v^e_{n+1} denotes the expected velocity of the preceding vehicle, i.e., the $(n+1)$th vehicle, at the time $(t+1)$; d_{n+1} is the empty sites in front of the $(n+1)$th vehicle, $d_{n+1}(t+1) = x_{n+2} - x_{n+1} - 1$; x_{n+1} and x_{n+2} denote the positions of the $(n+1)$th and $(n+2)$th vehicles at the time $(t+1)$ respectively; $v_{\max(n+1)}$ denotes the maximum velocity of the preceding vehicle.

Please cite this article in press as: L. Fei, H.B. Zhu, Analysis of traffic congestion induced by the work zone, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.01.036