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Energy dissipation of traffic flow at an on-ramp

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HIGHLIGHTS

- Investigate the energy dissipation of on-ramp traffic flow system.
- Explore the energy dissipation rates under different injected probabilities.
- Estimate the critical value of the injected probability with on-ramp situation.

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ABSTRACT

This paper proposes a new cellular automaton traffic model to study the energy dissipation in an on-ramp traffic system. Different from previous works, we investigate not only the traffic behavior in on-ramp flow system, but also the variation of energy dissipation in it. The numerical simulations are carried out and the influences of the injected probabilities and removed probability on energy dissipation are studied respectively. The results show there exist a critical point for the injected probability and a platform for energy dissipation. The results also indicate that the removed probability plays a chief role in avoiding traffic jam and reducing the energy dissipation, which is significant to explore the evolution of traffic congestion and the reduction of vehicle emission.

1. Introduction

The environmental pollution and energy consumption caused by traffic congestion have gained much attention in modern society. More than 20% of fuel consumption is produced by impeded traffic and go-and-stop traffic [1]. Vehicle emissions especially SO_2, NO_x, CO, CO_2 have been verified to be harmful to the urban environment and human health [1]. Recently some scholars have found that when the free traffic flow with velocity of 40 km/h change to the traffic jam with velocity of 10 km/h, the double fuel consumption will caused and 2–4 times environmental load will produced [2]. Therefore, it is extremely urgent to avoid traffic jam for improving the urban living quality.

In previous studies, the energy dissipation in traffic system has been investigated using the car-following model and many meaningful conclusions have been obtained [3–13]. Nakayama et al. [9] estimated the additional energy consumption of traffic flow by the action of the external disturbance. Shi et al. [10] studied the relation of the stability and energy consumption by analysis and comparison of energy consumption for several typical car-following models. Zhang et al. [11] obtained the relationships between the energy dissipation with the speed limit, the stochastic noise, the boundary conditions and the "go and stop" traffic. Tian et al. [12] and Ning et al. [13] investigated energy consumption of the mixed traffic flow and

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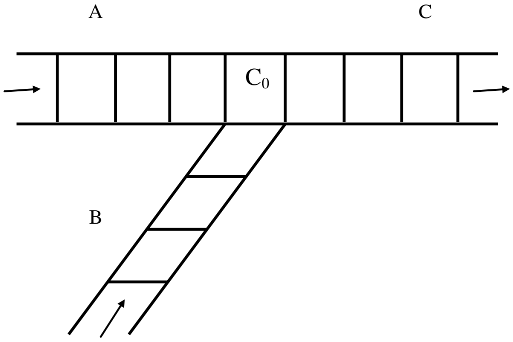

Fig. 1. Sketch illustration of the road (the road is divided into three sections: *A*, *B* and *C*).

synchronized traffic respectively. With these studies, the energy dissipation in one-way traffic system is well understood. However, the energy dissipation in the on-ramp traffic system is seldom investigated.

Cellular automata (CA) models are very efficient ways to implement the car motion. Compared with other dynamical approaches, the CA models are suitable to the complicated phenomenon observed in real traffic and have high efficiency for computer simulations, which have been extensively applied and investigated to date [14–26]. Diedrich et al. [25] and Campari and Levi [26] simulated the on-ramp traffic system using the CA models. At each time step, the lattice will be searched in the region of the on-ramp either successively or stochastically until a vacant cell is found. Then a car will be inserted into this cell with a chosen probability. Traffic phenomena such as synchronized flow, the lane inversion, and phase separation were reproduced and it is verified to be an effective tool. Based on it, the influence of varying injected and removing probabilities on energy dissipation in the on-ramp traffic system is studied using CA model in this study.

The paper is organized as follows. In Section 2, the structure of the on-ramp system and the energy dissipation model is proposed in details. The numerical simulation and discussion are carried out in Section 3. The summaries of our findings are drawn in Section 4.

2. Energy dissipation model

Motions of cars and interactions between cars are the microscopic processes in the traffic flow. One of the approaches to microscopic traffic processes is based on CA. A CA model treats the motion of cars as hopping processes on one-dimensional lattices. The Wolfram's rule-184 CA is the simplest choice. Nagel and Schreckenberg introduced their CA model (NS model) by extending the 184 CA to consider the high velocity and the stochastic processes [18]. The NS model is defined on a one-dimensional lattice of *L* sites with periodic boundary conditions. Each site is either occupied by a car, or is empty. The velocity of each car is an integer between zero and $v_{\max}$. The parameter of $v_{\max}$ is the allowed maximum velocity of all cars. The state of the system at the time $t+1$ could be obtained from the state at the time t by applying the following four rules to all cars at the same time [18]:

(1) acceleration: $v_n \to \min(v_n + 1, v_{\max})$
(2) deceleration: $v_n \to \min(v_n, gap_n)$
(3) randomization with probability p : $v_n \to \max(v_n - 1, 0)$
(4) motion: $x_n \to x_n + v_n$

where $x_n(t)$ and $v_n(t)$ denote the position and the velocity of the nth car at time t. $gap_n(t) = x_{n+1}(t) - x_n(t) - 1$ denotes the number of empty cells in front of ith car. p is the delay probability to simulate the driver's uncertain behaviors. All these rules are a necessity for mimicking the basic features of real traffic flow.

In reality, two main roads frequently connect and compose a special on-ramp system (Fig. 1). The traffic behavior in it is found to be different with the traffic behavior in NS model. Hence, in this paper we try to propose a new model to deeply investigate it. In the on-ramp system, there appear three road sections (A, B and C). The connecting cell is named C_0. The leading car on the sections A and B are denoted as A_{lead} and B_{lead} respectively while the last car on the section C is symboled as C_{last}.

At every time step, we firstly examine whether the car A_{lead} could be allowed to arrive in the position of the cell C_0 or not. If not allowed, it is obvious that the update of the cars in section A is not affected by those cars on section B, and vice versa. Similarly, we also do the same examination for the car B_{lead}. If both of the A_{lead} and B_{lead} cars do not occupy the cell C_0, the cars on sections A and B are not affected each other. If both of leading cars A_{lead} and B_{lead} want to occupy the same cell C_0 at the same time step, the situation become complicated. To deeply understand it, the arrival time t_a and t_b for cars A_{lead} and B_{lead} are defined [20]:

$$t_a = \frac{x_{C_0} - x_{A_{lead}}}{\min\left(v_{\max}, x_{C_{last}} - x_{A_{lead}} - 1, v_{B_{lead}} + 1\right)} \quad (1)$$