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Simulation of three lanes one-way freeway in low visibility weather by possible traffic accidents

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HIGHLIGHTS

- The real vehicle rear-end accidents on a freeway are studied.
- The improved CA model includes delayed reaction time and deceleration restriction.
- We proposed the rules of low visibility weather and handling a vehicle accident.
- The optimal strategies in different visibility are provided by the phase-space.

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ABSTRACT

The aim of this work is to investigate the traffic impact of low visibility weather on a freeway including the fraction of real vehicle rear-end accidents and road traffic capacity. Based on symmetric two-lane Nagel–Schreckenberg (STNS) model, a cellular automaton model of three-lane freeway mainline with the real occurrence of rear-end accidents in low visibility weather, which considers delayed reaction time and deceleration restriction, was established with access to real-time traffic information of intelligent transportation system (ITS). The characteristics of traffic flow in different visibility weather were discussed via the simulation experiments. The results indicate that incoming flow control (decreasing upstream traffic volume) and inputting variable speed limits (VSL) signal are effective in accident reducing and road actual traffic volume's enhancing. According to different visibility and traffic demand the appropriate control strategies should be adopted in order to not only decrease the probability of vehicle accidents but also avoid congestion.

1. Introduction

The bad weather is one of the important reasons causing traffic accidents. Especially, low visibility weather cannot guarantee enough safe sight distance, which, on the one hand, results in safety risks, i.e., a single collision and multiple collisions with decreasing the headway, and on the other hand, severely reduces the road actual traffic volume [1]. It makes impossible that the freeway exerts the advantages of high speed and large capacity. The freeway will be temporarily closed if the visibility drops down to a certain value by the traffic management department, i.e., 50 m according to the Announcement of the Freeway Traffic Management in Low Visibility Weather Conditions issued by the Ministry of Public Security of the People's Republic of China [2]. Is the value reasonable? If the visibility is low, what is a good control strategy for a minimal probability of vehicle accidents and maximal road actual traffic volume? As a result, it is necessary to investigate the traffic impact of low visibility weather on a freeway.

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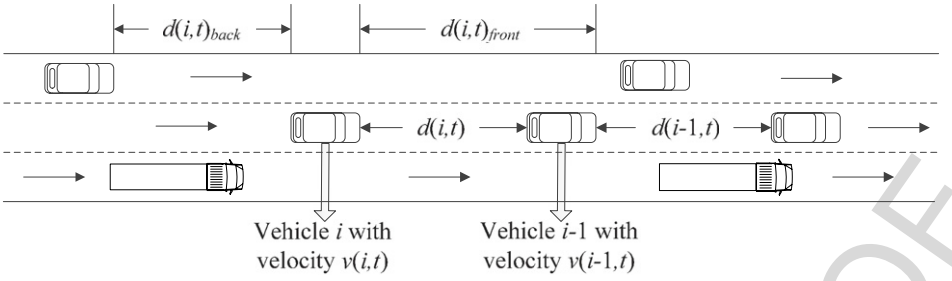

Fig. 1. Studied object.

As an excellent tool, cellular automata (CA) models have been used widely to study the traffic flow behaviors including model establishment, traffic flow characteristics, and some parameters' impacts. Especially many researchers have studied the occurrence of car accidents by using the extended CA models [3–11], i.e., the deterministic NS model proposed firstly by Boccara et al. [10]. On the whole, the study of traffic accident with CA model can be classified into two categories. Firstly, car accident does not really occur when the necessary conditions are simultaneously satisfied; these dangerous situations are calculated and considered to be the signal of the occurrence of accidents [3–7]. Obviously this does not conform to the actual road traffic. The actual nonlinear relation cannot be mapped in the models. Secondly, there is only one accident in the whole simulation [8,9]. Traffic accident really occurs, but the vehicle which results in the accident certainly appears in the pre-set time step or position. Obviously these conditions are too strict to satisfy for the actual traffic system. Vehicle accidents can happen anywhere and anytime, and even more than one vehicle accident may take place on the road at the same time, therefore both when and where vehicle accidents occur are random in real traffic systems [10,11]. At the same time, the effects of headway, velocity, relative velocity, density, and sensitivity on safety–collision transition have been discussed when a vehicle changes lane and the preceding vehicle suddenly slows down in some literatures [12,13]. The chain-reaction crash in low-visibility condition on a road has been studied [1]. Based on these and NS model we present a CA model of three lanes one-way freeway in the paper, where vehicle accidents do really occur when the necessary conditions are simultaneously satisfied and the sites and the times of the accident occurrences are random. The characteristics of traffic flow in different visibility weather and traffic demand were discussed and the different impacts were analyzed via the simulation experiments by using various control strategies.

2. CA model with the occurrence of vehicle accidents

As shown in Fig. 1, only one mainline on a freeway with no ramp, which possesses continuous traffic flow characteristics, is used as the research object to illustrate the problem. The mainline consists of three lanes, denoted as left lane, middle lane, and right lane. In normal traffic state meaning that no vehicle accident happens, a truck is forbidden to travel on the left lane. There is no lane-limited for a car. If a vehicle accident happens, there is no lane-limited for truck and car. Two speed limit values are set for car and truck, respectively. Each lane, where the length is L m, is divided into discrete cells. The length of each cell is equal to 1 m, which means that the number of cells of each lane is equal to the length of the mainline. Each cell may either be empty or be occupied by one vehicle with an integer velocity v between zero and the maximal speed limit $v_{\max}$, where we use $v_{\max 1}$ in place of $v_{\max}$ for a car and $v_{\max 2}$ in place of $v_{\max}$ for a truck and P_{car} denotes the proportion of car. Here $v_{\max}$ is a stable value when no variable speed limits (VSL) signal is inputted and a variable value when a VSL signal is inputted.

In order to describe the traffic flow processing of the studied object, we establish an extended three-lane CA model based on NS with the real occurrence of vehicle accidents in low visibility weather, which considers delayed reaction time, deceleration restriction, and velocity effect proposed by Xiao-bai Li [14]. Let d_{safe} denotes the safety distance between a vehicle and its preceding vehicle and it is a function of velocity, relative velocity, density, and the other state variables. Considering that relative velocity is the main influence factor, safety time headway is 2 s, and the complexity of the studied problem, its value is assumed to be 2 times of relative velocity as $2 \times (v(i,t) - v(i-1,t))$ in the model. Let $a1$ represents accelerated speed and its maximum is $D1_{\max}$, where $a11$ replaces $a1$ for a car and $a12$ for a truck. And $a2$ represents decelerated speed and its maximum is $D2_{\max}$, where $a21$ replaces $a2$ for a car and $a22$ for a truck. The position for vehicle i at time t is defined as $x(i,t)$. The first vehicle is marked as 1, and the following vehicles are marked as $2, 3, \ldots, i$. Here $d(i,t)$ denotes the empty cells between vehicle i with velocity $v(i,t)$ and its predecessor with velocity $v(i-1,t)$ at time t. $d(i,t)_{front}$ and $d(i,t)_{back}$ denote the empty cells between vehicle i and its preceding vehicle and its successor on the beside road, respectively.

2.1. Basic model

Under normal circumstances, the vehicle evolution rules are as follows.

(1) Acceleration, $v(i,t+1) = \min(v(i,t)+a1, v_{\max})$, indicating that the driver expects to maintain vehicle i at the maximal speed.

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