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An analysis of pileup accidents in highway systems

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HIGHLIGHTS

- A three-lane traffic flow model is proposed to analyze the vehicle collisions.
- The occurrence of pileup accidents is analyzed on a three-lane highway.
- Different vehicle collisions are evaluated based on four road driving strategies.
- Double lane-changing collisions produce an increase of the pileup accidents.
- Simulations show that the speeds of vehicles provoke a pileup accident noticeably.

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ABSTRACT

Pileup accident is a multi-vehicle collision occurring in the lane and producing by successive following vehicles. It is a special collision on highway. The probability of the occurrence of pileup accident is lower than that of the other accidents in highway systems. However, the pileup accident leads to injuries and damages which are often serious. In this paper, we analyze the occurrence of pileup accidents by considering the three types of dangerous collisions in highway systems. We evaluate those corresponding to rear-end collision, lane-changing collision, and double lane-changing collision. We simulate four road driving strategies to investigate the relationships between different vehicle collisions and pileup accidents. In accordance with the simulation and analysis, it is shown that the double lane-changing collisions result in an increase of the occurrence of pileup accidents. Additionally, we found that the probability of the occurrence of pileup accidents can be reduced when the speeds of vehicles are suitably constrained in highway systems.

1. Introduction

Improper driving behaviors and unexpected environmental changes in highway systems could result in the occurrence of vehicle accidents. The traffic accidents prevent the traffic flow and block the highway. A heavy congestion and injury will likely occur [1–4]. Hence, the analysis of traffic accidents becomes one of the most important issues in traffic management because it is associated with human life [5–7]. In order to reduce the occurrence of traffic accidents and to prolong human life, simulated investigations are highly desirable to evaluate the effect of traffic safety in terms of number of traffic accidents. In the past few years, the investigations of traffic flow have been proposed and analyzed in the field of physical science and engineering. Some traffic flows have been simulated with cellular automaton (CA) models because CA model is simple and can be easily implemented on computers for simulation study [8–19]. The Nagel–Schreckenberg (NS) model is a typical CA model for analyzing one-lane traffic flow [8]. Based on the NS model, CA models have been extended to study bidirectional traffic, two-lane, and three-lane traffic flow models [13–17]. In order to analyze the characteristics for the traffic flow, traffic

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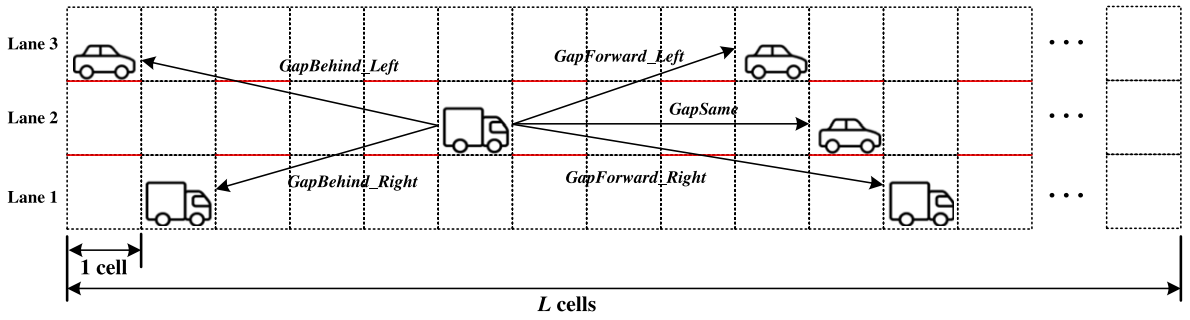

Fig. 1. Three-lane traffic model.

congestion, and lane density on highway, several rules for the acceleration, deceleration, lane changing, forward moving, and overtaking are proposed on the basis of the CA models. CA models have been extensively applied in various traffic scenarios. They have also been extended to investigate the occurrence of traffic accidents [2–5,17–19]. Nowadays, there are many occurrences of traffic accidents in real transportation systems. To make a reasonable plan for the traffic safety, it is important to evaluate the risk of traffic accidents. Because no one can make real crash tests with living drivers in real traffic environments, it is necessary to analyze the conditions for the occurrence of traffic accidents by simulation study. Several researches on traffic accidents have been conducted on transportation systems. The definitions of accident conditions and analytical models have been proposed, which have been validated to some extent through simulations. However, most of the previous works were focused on the traffic accidents on a single lane and bidirectional traffic systems [17–19]. It is obvious that a real highway system seldom consists of a single lane only. The pileup accident is a special collision on highway. It happens only when a traffic accident occurs in the lane and the following vehicles continue to cause collisions in the same lane. The pileup accident provokes injuries and damages which are often serious. Nevertheless, the analysis and discussion of pileup accidents in highway systems have been studied minimally.

Motivated by the above discussion, we propose a three-lane traffic flow model to analyze the probability of the occurrence of pileup accidents on highway by employing CA models. Accounting for the pileup accidents, we extend our previous work to analyze the occurrence of pileup accidents by considering the rear-end collision, lane-changing collision, and double lane-changing collision on a three-lane highway. Four road driving strategies (i.e. homogeneous strategy, symmetric strategy, asymmetric strategy, and constraint-based strategy) for analysis and discussion are taken into account [2]. We evaluate the impact on the different vehicle collisions and pileup accidents based on different road driving strategies. Simulation results indicate that the double lane-changing collisions produce an increase of the occurrence of pileup accidents. The main benefit of this paper is precisely the investigation of the probability of collisions in three-lane traffic flow models and to analyze the effects on the vehicle's velocity and probability of the occurrence of pileup accidents in different road driving strategies. According to the simulation and analysis, we found that the speeds of vehicles influence the pileup accidents noticeably. To reduce the risk of pileup accidents on highway, it is necessary to limit the speeds of vehicles to a reasonable region.

The remainder of this paper is organized as follows. In Section 2, we present a system model for three-lane traffic. In Section 3, we illustrate the conditions for the occurrence of vehicle accidents in detail. In Section 4, we present our simulation model and analyze the comparative evaluation results through simulations. Finally, conclusions are presented in Section 5.

2. System model

In this paper, we consider a three-lane traffic model to analyze the probability of the occurrence of pileup accidents on highway by using a CA model with periodic boundary [2]. There are three lanes in the system model. We assume that lane 1 is an outer lane, lane 2 is a center lane, and lane 3 is an inner lane. All of the vehicles will move from left to right in the three lanes. Fig. 1 illustrates a three-lane traffic model, where each lane is divided into L cells. Each cell location is either empty, or occupied by just one vehicle. It denotes a temporary location for the vehicle to keep its moving situation. Two kinds of vehicles move from left to right: fast and slow vehicles (e.g. cars and trucks). In accordance with the forward moving rules, all of the vehicle locations could be updated for each unit time. Let $X(k, n, t)$ be the location of vehicle k in lane n at time t. The new location of vehicle k in lane n at time $t + 1$ can be calculated by

$$X(k, n, t + 1) = X(k, n, t) + V(k, n, t + 1), \tag{1}$$

where $V(k, n, t + 1)$ is the speed of vehicle k in lane n at time $t + 1$. We define five distance parameters to determine the vehicle speed and lane changing at next unit time. Table 1 shows the parameters used in system model. The system update is performed in parallel for all of the vehicles at each discrete time according to the forward moving and lane changing rules.

2.1. Forward moving rules

We assume that all of the vehicles are restricted to move in one direction only. In order to fit the real road driving situations, two environmental parameters are taken into account in the forward moving rules. Let P_{increase} be the probability