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Multiple-vehicle collision induced by lane changing in traffic flow

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HIGHLIGHTS

- We studied the multiple-vehicle collision when a vehicle changes its lane to a target lane.
- We derived the region map for the multiple-vehicle collision induced by lane changing.
- We clarified the dependence of the multiple-vehicle collision on the driver's characteristic and the traffic situation.

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ABSTRACT

We study the multiple-vehicle collision when a vehicle changes from the first lane to the second lane on a two-lane highway. If a vehicle with high (low) speed on the first lane enters into the second lane, it may crash into the forward (rear) vehicle on the second lane and the crash may induce more collisions. We investigate whether or not the incoming vehicle induces the multiple-vehicle collision. The number of collisions depends on the initial velocity, the initial density, the incoming velocity, the incoming headway, the sensitivity, and the relative velocity. We derive the region map for the multiple-vehicle collision induced by lane changing.

1. Introduction

Mobility is nowadays one of the most significant ingredients of a modern society. Traffic flow is a self-driven many-particle system of strongly interacting vehicles [1–5]. The concepts and techniques of physics are being applied to such complex systems as transportation systems. Several physical models have been applied to the vehicular flow [6–35]. The dynamical phase transitions such as the jamming transitions between distinct traffic states have been studied from a point of view of statistical physics and nonlinear dynamics.

Traffic accident is dangerous, inducing severe congestions, and preventing mobility. In real traffic, a heavy congestion occurs when a traffic accident happens. The accident prevents the traffic flow and blocks the highway. The car accident occurs sometimes when a vehicle changes its lane. In order to avoid a collision with vehicles ahead or behind in the process of lane changing, a sufficiently long headway between the vehicles ahead or behind is necessary. Also, it is necessary and important that the speed of the incoming vehicle is not high or not low in comparison with that of the vehicles ahead or behind. The collision with vehicles ahead or behind will depend on the density, the incoming headway, the incoming speed, driver's sensitivity, and velocity difference. It is important and necessary to know the conditions of collision (or crash) when the vehicle changes the lane. Naito and Nagatani have studied the single collision induced by lane changing. The condition of the single collision has been explored by using the optimal velocity model [36].

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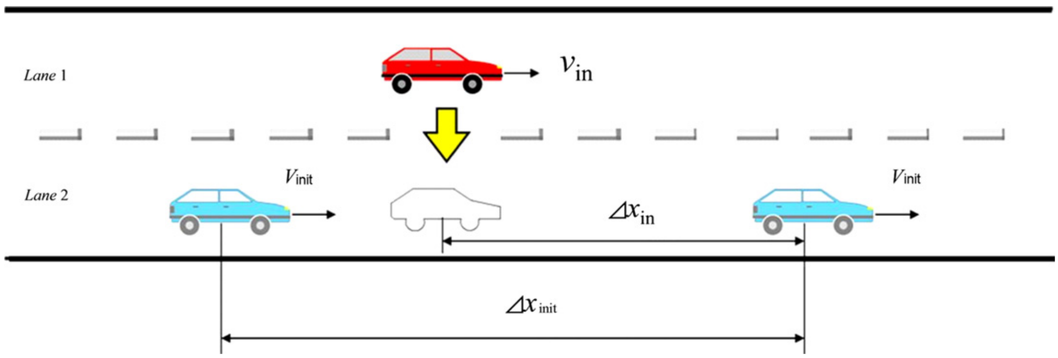

Fig. 1. Schematic illustration of the dynamic model for lane changing on the two-lane highway. The incoming vehicle enters into the position with headway Δx_{in} from the vehicle ahead. The velocity of the incoming vehicle is v_{in}. All vehicles on the second lane move with the same headway Δx_{init} and speed v_{init}.

The crash by lane changing may induce more collisions and may result in the multiple-vehicle collision. The multiple-vehicle collision is a road traffic accident involving many vehicles. The mass of crumpled vehicles depends greatly on the traffic situation and drivers. The multiple-vehicle collision induced by a sudden slowdown has been investigated by Sugiyama and Nagatani [37]. However, the multiple-vehicle collision induced by lane changing has not been studied by using the modern traffic models. It is little known how much speed and how long headway between the vehicles ahead or behind is necessary to avoid the multiple-vehicle collision.

In this paper, we present the dynamic model for the process of lane changing on a two-lane traffic flow. We apply the extended optimal-velocity model to the vehicular motion on a two-lane highway. We study the multiple-vehicle collision when the vehicle changes from the first lane to the second lane. We investigate whether or not the incoming vehicle induces the multiple-vehicle collision. We derive a criterion that the incoming vehicle comes into collision with the vehicles ahead or behind and the crash induces more collisions. We show the dependence of the mass of the crumpled vehicles on the traffic condition. We find the region map for the multiple-vehicle collision induced by lane changing.

2. Model

We consider the situation that many vehicles move ahead on a two-lane highway. Drivers sometimes try to change their lane to the target lane. If the lane changing does not occur frequently, it will be sufficient to investigate the process that a single vehicle on the first lane tries to change to the second lane. We study the case that a vehicle on the first lane tries to change its lane to the second lane with vehicular speed v_{in}. Here, we assume that all vehicles on the second lane move with the same headway Δx_{init} and speed v_{init}. Fig. 1 shows the schematic illustration of the dynamic model for lane changing on the two-lane highway. The incoming vehicle enters into the position with headway Δx_{in} from the forward vehicle where $\Delta x_{in} < \Delta x_{init}$.

When a vehicle on the first lane enters into the second lane, the incoming vehicle decelerates to avoid the collision with the forward vehicle. Also, the rear vehicle decelerates not to collide with the incoming vehicle. If the headway is not sufficiently long and the speed is high, the incoming vehicle may come into collision with the forward vehicle. If the headway is long and the speed is low, the rear vehicle may collide with the incoming vehicle. The crash may induce more collisions. We study whether or not the multiple-vehicle collision occurs.

We define collision parameter $S(\Delta x_i)$ as $S(\Delta x_i) \equiv \frac{v_i(t)}{\Delta x_i(t)}$ in order to judge whether or not vehicles collide with vehicle in front [37]. Here, $v_i(t)$ and $\Delta x_i(t)$ are the velocity and headway of vehicle i at time t. When vehicle i comes into collision with the vehicle in front, the collision parameter diverges. On the other hand, if vehicle i can stop without collision with the vehicle in front, the speed approaches zero, $S(\Delta x_i) = 0$.

Even if vehicle i approaches extremely close to the vehicle in front without a collision, the collision parameter approaches zero because velocity $v_i(t)$ converges to zero faster than headway $\Delta x_i(t)$ for no collision. When vehicle i moves safely with keeping a proper headway, collision parameter becomes a finite value. Thus, one can classify the traffic into three states by the collision parameter: (a) a stopping state with no collision, $S(\Delta x_i) = 0$, (b) a moving state, $S(\Delta x_i) = a$ finite value, and (c) a collision, $S(\Delta x_i) = \infty$.

Therefore, collision parameter $S(\Delta x_i)$ is suitable to judge the traffic states for collisions. Also, the collision parameter is related to the risk of collision. One can reduce the risk of collision by decreasing the value of the collision parameter. We assume that two vehicles stop instantly if they contact one another.

We apply the extended optimal velocity model to the vehicular motion to take into account the velocity difference [1,28,33–37]. If the speed of the vehicle is close to that of the forward vehicle, the possibility of collision with the forward vehicle reduces. When a driver tries to change his lane to the target lane, the driver accelerates or decelerates to follow the speed of the forward vehicle on the target lane. Thus, it is necessary to apply the extended optimal velocity model to the lane changing problem to take into account the velocity difference between the vehicle and the forward vehicle.