Multiple-vehicle collision influenced by misjudgment of space headway in traffic flow under fog weather condition

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Abstract. The multiple-vehicle collision easily happens under fog weather condition. To illustrate the effect of misjudgment of space headway on the multiple-vehicle collision in traffic flow, this paper derives collision criterion of the car-following model including risk illusions in fog weather (RIFM). Numerical simulations are carried out by varying driver’s sensitivity, vehicular density and initial velocity. This paper obtains the region map for the multiple-vehicle collision when a vehicle stops suddenly in traffic flow. The results indicate that although under low density conditions, the collision will happen just because of the misjudgment of space headway. In general, when drivers are affected by the misjudgment of space headway, the number of crumpled vehicles has positive correlation with initial velocity and vehicular density, and negative correlation with driver’s sensitivity. Therefore, in order to ensure traffic safety, the initial velocity and vehicular density should be reduced, and driver’s sensitivity should be increased under fog weather condition.

1. Introduction

The multiple-vehicle collision easily happens under fog weather condition. According to statistics, the death toll in fog weather was 0.469 for each road accident, which ranked first in adverse weather conditions [1].

The causes of traffic accidents under fog weather condition have been studied from the perspective of driving behaviors [2-5]. Broughton et al. found that the space headway would be shortened under fog weather condition [2]. Saffarian et al. suggested that keeping a relatively close distance would reduce driver’s feeling of risk in fog weather [3]. However, most drivers were not aware they had shortened the space headway [4]. Duan et al. explained this irrational behavior as risk illusions [5]. Obviously, the misjudgment of space headway will increase the risk of collision.

Driving behaviors can be described by traffic flow model [6-13]. Shi and Tan proposed improved cellular automaton models considering driving behaviors in heavy fog, in order to study freeway intermittent release measures [9-10]. Tan developed an extended car-following model (RIFM) to investigate driver’s risk illusions in fog weather [13]. In the RIFM, the misjudgment of space headway is a risk factor. The risk of road traffic accidents can be measured based on the car-following model [14-16]. Sugiyama and Nagatani derived the collision criterion of optimal velocity (OV) model and studied the factors affecting the multiple-vehicle collision [14]. Li and Chen investigated the possibility of the multiple-vehicle collision induced by a sudden stop while considering the effects of the intelligent control mechanism [15]. Nagatani explored the effects of the velocity-dependent friction force on the multiple-vehicle collision [16].

However, the multiple-vehicle collision in traffic flow influenced by the misjudgment of space
headway has not been studied under fog weather condition. Therefore, in this paper, the collision criterion of RIFM is derived on the basis of the existing researches [14-16]. Numerical simulations are performed to investigate the effects of the misjudgment of space headway on multiple-vehicle collision under different sensitivity, vehicular density and initial velocity.

2. Model and Collision Criterion
Tan proposed a car-following model including risk illusions in fog weather (RIFM) [13]. In the RIFM, there is a certain difference between driver’s judging value and the actual value of the space headway under fog weather condition. If \( \gamma \) represents the ratio of the judging value to the actual value, then \( \gamma \times \Delta x_n(t) \) refers to driver's judging value of the space headway. Under fog weather condition, the speed limit will be decreased for safety purpose. This paper takes \( \kappa \) to adjust the speed limit, where \( 0 < \kappa < 1 \). The position of vehicle \( n \) at time \( t \) is \( x_n(t) \), the headway is \( \Delta x_n(t) \), and \( \Delta x_n(t) = x_{n+1}(t) - x_n(t) \), the velocity is \( v_n(t) \), then the acceleration is described as [13]:

\[
\frac{d^2 x_n(t)}{d t^2} = \alpha \left[ V_f(\Delta x_n(t)) - v_n(t) \right] + \beta \Delta v_n(t) + \lambda F(\Delta x_n(t))
\]

(1)

where \( \alpha \), \( \beta \) and \( \lambda \) are sensitivity parameters. The function \( F(\Delta x_n(t)) = \tanh(\Delta x_n(t) - d) \) is introduced to describe the driving behavior of speeding up unintentionally when the headway is beyond the comfortable range \( d \). With consideration of the misjudgment of space headway, the optimal-velocity function is formulated as [13]:

\[
V_f(\Delta x_n(t)) = \kappa \left[ V_1 + V_2 \tanh[C_1(\gamma \Delta x_n(t) - l_c) - C_2] \right]
\]

(2)

According to the collision criterion proposed by Sugiyama and Nagatani, vehicle \( n \) comes into collision with the vehicle in front when the headway between them tends to zero, and the velocity \( v_n(t) \) approaches to a constant \( C \) (\( C > 0 \)) [14]. In the RIFM, assuming the vehicle length is \( l_c \), the criterion for a collision is:

\[
\Delta x_n(t) - l_c \rightarrow 0, \text{ and } v_n(t) \rightarrow C
\]

(3)

3. Numerical Simulations
This paper uses MATLAB R2016b to simulate the dangerous situation when a vehicle stops suddenly in traffic flow [14]. The simulations are carried out under the periodic boundary condition. Initially, \( N \) vehicles are uniformly distributed on the highway with a total length \( L \). The vehicular density is defined as \( \rho = N \times l_c / L \), where \( N = 100 \), \( l_c = 5 \). In addition, \( \kappa = 0.8 \), \( \beta = 0.2 \), \( \lambda = 0 \), \( C_1 = 0.13 \), \( C_2 = 1.57 \), \( V_1 = 6.75 \), \( V_2 = 7.91 \) and the time step is \( \Delta t = 1/1000 \text{ s} \).

3.1. Effect of \( \gamma \) on multiple-vehicle collision
Figure 1 depicts the trajectories for vehicles behind the suddenly stopped vehicle with initial velocity \( v_0 = 40 \text{ km/h} \), sensitivity \( \alpha = 1.0 \). Figure 1(a) is corresponding to the situation without misjudgment of space headway (\( \gamma = 1.0 \)). Three trajectories denote the movement of the first, second and third vehicles behind the initially stopped vehicle. It shows that when a vehicle stops suddenly, the first vehicle decelerates rapidly to stop before the space headway decreased to 5 meters, indicating there is no collision. Figure 1(b) is corresponding to the situation with misjudgment of space headway (\( \gamma = 1.2 \)). When a vehicle stops suddenly, the first vehicle begins to decelerate as well. However, when the first vehicle approaches to the stopped vehicle, its velocity is greater than zero. According to equation (3), there will be a collision. In figure 1(c), both the first and the second vehicles come into collision with their preceding vehicles. The results suggest that the misjudgment of space headway
will increase the probability of collision. Moreover, the occurrence of collision is easier under higher vehicular density.

![Figure 1](image1.png)

**Figure 1.** Trajectories for vehicles with $v_0 = 40 \text{ km/h}$, $\alpha = 1.0$.

To further investigate the effect of misjudgment of space headway on the collision, this paper simulates the number of vehicles involved in the multiple-vehicle collision by varying $\rho$ and $\alpha$. The value range of density $\rho$ is $(0, 0.8]$, and that of sensitivity $\alpha$ is $[1.0, 3.0]$. The simulation results are displayed in figure 2, which indicate that the number of crumpled vehicles grows as the density increases. In figure 2(a), there is a vehicle collides to the preceding vehicle when $\rho = 0.36$. In figure 2(b), due to the misjudgment of space headway, collision happens when the density decreases to $\rho = 0.28$. It is clear that the misjudgment of space headway will lead to collisions under low-density conditions. Additionally, for high sensitivity, few collisions occur. This is because the sensitivity is the reciprocal of driver's reaction time. Larger value of sensitivity means shorter reaction time. Therefore,
vehicles can be braked in time and the collision can be avoided.

Figure 2. Number of the crumpled vehicles with different $\gamma$ when $v_0 = 40$ km/h.

3.2. Effect of initial velocity on multiple-vehicle collision with certain $\gamma$

In figure 3(a), there are three vehicles colliding to their preceding vehicles when $\gamma = 1.2$ and the initial velocity is $v_0 = 60$ km/h. In figure 1(c), there is only a double-vehicle collision by merely changing the initial velocity to $v_0 = 40$ km/h. Correspondingly, figure 1(b) shows that only the first vehicle collides to its preceding vehicle when the initial velocity is $v_0 = 40$ km/h. However, in figure 3(b), both the first and the second vehicles collide to their preceding vehicles when the initial velocity increases to $v_0 = 60$ km/h. Evidently, the higher the initial velocity, the more probable the collision will occur.

Figure 4 depicts the number of vehicles involved in the multiple-vehicle collision under different initial velocity when $\gamma = 1.2$. In figure 4(a), the collision firstly occurs at point (0.16, 1.0) under the initial velocity $v_0 = 60$ km/h, and the number of crumpled vehicles reaches 12 when $\rho = 0.8$. However, when the initial velocity decreases to $v_0 = 20$ km/h in figure 4(b), the region of the multiple-vehicle collision shrinks to the high-density side, and the number of crumpled vehicles
clearly reduces. Obviously, a higher velocity will induce more collisions with certain $\gamma$.

![Image of trajectories for vehicles with $v_0 = 60\text{ km/h}$, $\alpha = 1.0$.](image)

![Image of number of crumpled vehicles under different $v_0$ when $\gamma = 1.2$.](image)

### 4. Conclusions

In this paper, the collision criteria of the RIFM is derived. Through numerical simulations, the effects
of driver’s misjudgment of space headway on the multiple-vehicle collision are clarified under different vehicular density and initial velocity. For one thing, the misjudgment of space headway increases the possibility of the collision. For another thing, when the collision occurs, the misjudgment will increase the number of crumpled vehicles. The results could explain why foggy days are prone to serious multiple-vehicle collision.

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