Abstract

Rear-end collisions and lane-changing collisions are two most common types of automobile collision in multi-lane freeway traffic conditions, and they are dangerous in disaster weather. Car-following behavior, which describes the behavior of a vehicle while following the vehicle in front of it, has a significant impact on traffic safety. One of the most possible behavior leading to rear-end collisions is studied in this paper. In addition, car-following is one of the essential components of microscopic traffic models. In this paper, we estimate the emergency braking distance of passenger vehicles with respect to vehicles moving in the same lane. Lane-changing behavior which describes a vehicle changes its lane into the other lane according to the accurate gap-acceptance decisions theory. Lane-changing related to collisions prone to occur in the process of lane-changing maneuvers. Lane-changing theoretical models and operational risk are studied in this paper to reveal the essence of traffic flow characteristics of the multi-lane freeway at the microscopic level. In summary, the paper presents a flexible framework for modeling car-following behavior and lane-changing behavior, which relaxes some constraints and assumptions of the most commonly used car following models and lane-changing models.

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Key Words: multi-lane freeway; disaster weather; rear-end collisions; lane-changing collisions; operational risk

1. Introduction

Traffic problem has attracted considerable attention of many scholars lately. In real traffic, the behaviors of lane-changing and car-following often occur in multiple lanes. Car-following behavior and lane-changing behavior will be the most danger two driving behaviors prone to traffic conflict and collisions. Recently, there are a few models to study the lane-changing and car-following behavior in multi-lane traffic. But the above studies do not give consideration to the anticipation effect of potential lane changing on the dynamic equation. Very recently, some researchers proposed a car-following model by considering the anticipation effect of the lane changing probability of the leading vehicle on the car-following behavior of the following vehicle on single lane. However, the anticipation effect of the lane changing probability of the leading vehicle has not been studied in
lattice models of traffic flow. The results indicate that these models may be applied for identifying real-time traffic conditions prone to lane-change related crashes.

In this paper, we present some new models of traffic flow by taking the anticipation effect of the lane changing probability into account. Lane-changing theoretical models and operational risk will be studies to reveal the essence of traffic flow characteristics of the multi-lane freeway at the microscopic level. However, the conditions preceding crashes are expected to differ by type of crash and therefore the approach towards proactive traffic management should be type (of crash) specific in nature.

2. Background

Initial studies on car-following behavior developed models which capture situations where the subject vehicle reacts to the leader’s actions (Reuschel, 1950; Pipes, 1953). Later on, several researchers developed general acceleration models which also capture the behavior of drivers in other situations, such as car-following, free-flowing, and emergency (Yang and Koutsopoulos, 1996; Ahmed, 1999; Toledo, 2003).

Over the past decade, several car-following models have been proposed and described in the literature. Brackstone and McDonald (1999) categorized car-following models into five groups, namely: Gazis–Hereman–Rothery (Gazis et al., 1961) models, safety distance collision avoidance models (Kometani and Sasaki, 1959; Gipps, 1981), linear models (Helly, 1959) psycho-physical or action point models (Wiedemann, 1974), and fuzzy logic based models (Kikuchi and Chakroborty, 1992).

Treiber et al. (2006) were interested to examine whether the destabilizing effects, such as finite reaction times and estimation errors, are compensated for by temporal and spatial anticipation (looking several vehicles ahead) of drivers, named as the stabilizing effects. To test that, the authors extended the Intelligent Driver Model (Treiber et al., 2000) by assuming: (a) infinite reaction times, (b) estimation errors, (c) spatial anticipation, and (d) temporal anticipation. The GM family of models has been estimated using trajectory data (Ahmed, 1999; Toledo, 2003). The estimation of the model assumes that a driver accelerates when the relative speed $DV_{front}$ is positive, and decelerates when $V_{front}$ is negative. Wiedemann (1974) and Leutzbach (1988) address two limitations of many GM-type models from a behavioral standpoint: that drivers remain affected by the actions of their leader even when the spacing between them is large, and that drivers are able to perceive and react to even small changes in the stimulus. To overcome these limitations they introduced the psycho-physical model which uses “perceptual thresholds”. Perceptual thresholds are a function of space headway and relative speed between the following and followed vehicles. It is assumed that drivers do not react unless these thresholds are reached and therefore it captures the increased awareness of drivers for small headways and lack of following behavior at large headways. It was found that the perceptual thresholds for acceleration differ from those of deceleration decisions.

Hamdar and Mahmassani (2008) calibrated, and tested several existing car-following models using the NGSIM (Next Generation SIMulation) data. The authors tested these models in terms of vehicle trajectories, flow-density relationships and ability to model driver behavior during incident conditions. Tordeux et al. (2010) developed a car-following model based on time gap and estimated it using maximum likelihood method. These results revealed significant differences between vehicle types and between acceleration and deceleration situations. Regarding vehicle types, it was found that motorcyclists tend to accelerate more sharply than cars and trucks whereas trucks were found to decelerate more intensely. Since bottlenecks (Hall and Agyemang-Duah, 1991) and accidents (e.g., Golob et al., 2004) tend to occur in these areas, it is important to understand phenomena associated with lane-changing traffic. In this study, we assume that different lanes are balanced on average; i.e., vehicle speeds are the same across different lanes at the same location and time. In reality, it has been observed that traffic is nearly balanced inside major weaves, where speed difference for weaving and non-weaving vehicles is not statistically significant (about 5 mph) (Roess et al., 1974). Actually, imbalance among different lanes is usually areas on for lane-changing, and lane-changing traffic can have balancing effect; i.e.,
under certain situations, lane-changes could smooth out differences between lanes, and the balancing effect could be beneficial to the whole traffic system in achieving higher capacity. At the microscopic level, vehicles’ speed adjustment behavior have been modeled by car-following models (Gazis et al., 1961); similarly, lane-choice behaviors on why, when, where, and how a vehicle changes its lane are modeled by lane-changing models (Gipps, 1986; Yang, 1997; Toledo et al., 2003; Kesting et al., 2007). These models can describe detailed lane-changing behaviors, but usually contain a large number of parameters and cannot provide intuitive descriptions of system-level effects of lane-changing traffic. At the macroscopic level, many studies have been carried out to understand various characteristics of lane-changing traffic, including exchange of flows between lanes (Michalopoulos et al., 1984; Holland and Woods, 1997; Daganzo, 2002; Coifman, 2003), density oscillation and instability issues (Gazis et al., 1962; Munjal and Pipes, 1971), First-In–First-Out violation among vehicles (Jin et al., 2006).

3 Field Traffic Investigations

In order to study the car-following and lane-changing theoretical models of the multi-lane freeway, the Suzhou segment of the Shanghai-Nanjing freeway was selected as the field test site. Shanghai-Nanjing freeway began to expand from May 2003, and completed on January 2006. Shanghai-Nanjing freeway become two-way eight-lane freeway after expanded, therefore, traffic flow become more smoothly and fast, a little more than two hours from Nanjing to Shanghai. The traffic flow parameters, lane-changing and car-following driving behavior, geometric parameters of Shanghai-Nanjing multi-lane freeway common segments were studied in this paper. In order to study the driving behavior characteristics and traffic parameters of space-time trajectory in merging, diverging and weaving areas of multi-lane freeway interchange, and do field test in north Suzhou interchange. Figure 1 shows the Shanghai-Nanjing multi-lane freeway, and figure 2 shows the field test site.

4 Car-following Model

4.1 Car-following Analysis

In the medium or heavy traffic condition, the vehicle degree of freedom decreases with the increase in the density of traffic flow, and the traveling state of the vehicles are in the limited conditions at this moment, including car-following running state. In this state, the vehicles orderly queuing traveling, hence the traveling state and characteristic of the individual vehicle will be decided by the overall movement characteristics of the traffic flow, but a little affected by the vehicle characteristics and personality of the driver. Studies have shown that the vehicles in car-following state be provided with three typical characteristics: restrict, delay and transitivity.
In essence, the process which vehicle in the car-following state is a traffic behavior "assimilation" process between different drivers, and the running speed of the vehicle in front and after the car are broadly similar. The drivers constantly choose to adjust the speed in accordance with the speed of the vehicle in front, the vehicle spacing, the vehicle own speed, acceleration and other conditions so as to avoid rear-end collision occurs between vehicles. It shows that the car-following driving is a restriction-vehicle car driving state. Figure3 shows different accident types and factors statistics.

4.2 Security Constraints Control Model of Car-following

Vehicles which were conducting car-following driving behavior should avoid rear-end collision occurs with the vehicle in front. In other words, the security constraints of car-following are the safe distance, it is that the front car emergency brake, driver of the following car can be a timely response and carry out braking operation avoid the vehicle rear-end collision occurs. Figure 4 shows the description of the safe following distance with respect to braking.
During the driver's reaction time and vehicle braking time, whether the distance of the vehicle greater than the distance between vehicles as discrimination based on car-following safety, the various parameters calculated as shown below specific elaboration. Figure 4 shows the car-following and speed-change behavior (relative distance).

4.2.1 Motion state analysis of the vehicle $n$ ahead

Assume the vehicle emergency brake from the beginning of time $t_n$ and stop at time $t_n + \Delta t_n$, hence the braking distance was:

$$X_n(t_n + \Delta t_n) - X_n(t_n) = \frac{V_{n1}^2}{2g(\mu + i)} + \frac{V_{n1}^2}{254(\mu + i)}$$  

where $X_n(t)$ and $X_n(t_n + \Delta t_n)$ represent the locations of the vehicle $n$ at time $t$ and $t_n + \Delta t_n$; $\Delta t_n$ is the braking time of the vehicle $n$, $l$ is the pavement longitudinal adhesion modulus; $i$ represents longitudinal slope. Figure 5 shows that the lead gap and lag gap trajectories of field data.

4.2.2 Motion state analysis of the following vehicle

After the driver of the vehicle $n+1$ go through the reaction time to carry out brake operation, and stop in the location of $X_{n+1}(t + \Delta t_n)$, hence the braking distance was:

$$X_{n+1}(t + \Delta t_n) - X_{n+1}(t) = \frac{V_{n+1}^2}{3.6} + \frac{(V_{n+1}/3.6)^2}{2g(\mu + i)} + \frac{V_{n+1}^2}{254(\mu + i)}$$  

Where $X_{n+1}(t)$ and $X_{n+1}(t + \Delta t_n)$ represent the locations of the vehicle $n+1$ at time $t$ and $t + \Delta t_n$; $V_{n+1}$ represents the speed of the vehicle $n+1$, km/h; $\mu l$ is the pavement longitudinal adhesion modulus; $i$ represents longitudinal slope.

4.2.3 Locations relationship analysis of the vehicle in front and following

At time $t$, the spacing of the vehicle $n$ in front and the following vehicle $n+1$ represented by the following formula:

$$S(t) = X_n(t) - X_{n+1}(t) = \frac{V_{n+1}h_{n+1}}{3.6}$$  

Figure 5 Lead gap and lag gap trajectories of field data
In the formula, $V_n(t)$ represents the speed of the vehicle $n$ at time $t$, $V_n^i$ represents the speed of the vehicle $n$ and the following vehicle $n+1$, $h_{n+1,n}$ represents the headway of the vehicle $n$ and the following vehicle $n+1$, $s$; Figure 6 shows space headway (or reaction time) from trajectories of leading and following vehicles.

![Figure 6 Space headway (or reaction time) from trajectories of leading and following vehicles](image)

4.2.4 Car-following safety constraints

Analyze from the safety aspects, the vehicle in front and following brake spacing should be greater than the minimum safe distance $L$. $L$ includes a safe stopping distance (value 2m) and the body of the vehicle in front of $n$ (the length of the car designed for 2m, truck design length of 12 m, saddle-train design length of 12 m in length)

$$
\frac{V_n^2}{254(\mu \pm \epsilon)} + \frac{V_n h_{n+1,n}}{3.6} + \frac{V_{n+1}^2}{254(\mu \pm \epsilon)} + L\
$$

(4)

Finishing inequality:

$$
h_{n+1,n} \geq \frac{V_n^2}{70.56(\mu \pm \epsilon)} + \frac{V_n \tau}{V_n} + \frac{3.6L}{V_n}
$$

(5)

In addition, considering the impact of fog on the driver's reaction time. It is that the driver's reaction time includes normal reaction time delay and fog reaction time delay, Vehicle $n$ and the following vehicle $n+1$ car-following safety constraints is following:

$$
h_{n+1,n} \geq \frac{V_n^2}{70.56(\mu \pm \epsilon)} + \frac{V_n \tau + r_w}{V_n} + \frac{3.6L}{V_n}
$$

(6)

In summary, on the basis of the model of classic vehicle safety brake, and considered the fog response delay time and the road longitudinal adhesion coefficient, the impact of severe weather events such as fog, rain, snow and ice fusion with the vehicle safety model, and the model could be used to evaluate the operational risk of car-following behavior.

4.2.5 Driving lag reaction model in fog

To consider the influence of driving sight distance when the driver driving in fog, the concept of fog-caused driving lag time (FDLT) was proposed, that is when the visibility is less than the safety sight distance, in the lag reaction time which is reserved for the driver's, the speed of vehicles remains unchanged in the lag response period in order to ensure the safety of the vehicles within the range of low visibility, and the calculation model are following:

$$
\begin{align*}
\left\{ \frac{V_n \times (\tau_s + r_w)}{3.6} + \frac{(V_n / 3.6)^2}{2a_n} \right\} \\
\leq \left( 2S_d - S_{fog} \right) \\
S_{fog} \leq S_d \\
S_{fog} > S_d
\end{align*}
$$

(7)
Where $V_n$ represents speed of vehicle $n$, km/h; $\tau_s$ represents normal driving reaction time in good sight distance, value of $0.4 \sim 1.5$ s; $\tau_w$ represents driving response lag time in fog, s; $a_n$ represents normal deceleration of the vehicle $n$, value of $2 \sim 3$ m/s$^2$; $s$ represents the driver’s safe sight distance threshold, m; $s_w$ represents visibility distance in fog, m.

Table1. Different range of visibility fog driving reaction lag time (s)

<table>
<thead>
<tr>
<th>Vehicle speed (km/h)</th>
<th>Safety distance Threshold(m)</th>
<th>Visibility range(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50~100</td>
</tr>
<tr>
<td>60 km/h</td>
<td>85 m</td>
<td>1~3 s</td>
</tr>
<tr>
<td>80 km/h</td>
<td>130 m</td>
<td>3~6 s</td>
</tr>
<tr>
<td>100 km/h</td>
<td>190 m</td>
<td>6~7 s</td>
</tr>
<tr>
<td>120 km/h</td>
<td>255 m</td>
<td>7~9 s</td>
</tr>
</tbody>
</table>

Note: ① Deceleration values 3 m/s$^2$; ② Normal driving reaction time values 1.0 s.

Table2. Speed reductions in disaster weather

<table>
<thead>
<tr>
<th></th>
<th>Light rain</th>
<th>Heavy rain</th>
<th>Light snow</th>
<th>Heavy snow</th>
<th>Night</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liang et al.(1998)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>19.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kyte et al.(2000)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.5</td>
<td>9.1</td>
</tr>
<tr>
<td>Bemardin et al.(1995)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>13%</td>
</tr>
<tr>
<td>Ihreim and Hall(1994)</td>
<td>2</td>
<td>5-10</td>
<td>3</td>
<td>38-50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Brilon and Ponzlet(1996)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>9.5*12**</td>
<td></td>
</tr>
</tbody>
</table>

Unit: km/h,*-4lanes,**-12lanes.

It could deduced from Table1 that fog driving reaction lag time will increases 2s when speed 20 km / h for each additional, that is, in order to ensure the safety of the vehicle, the higher speed the longer time should be reserved for the driver reaction delays. Meanwhile, fog driving reaction time gradually decreases with the increased visibility range, and the decrease is about 3s, and it shows that the fog influence in driver gradually littler. In summary, fog driving reaction lag time decreases with the increased visibility range, the driving reaction lag time in fog gradually increasing as the speed increases.

5 Lane-changing model

5.1 Lane-changing Analysis

In medium traffic flow state, lane- changing distance exists in traffic flow, and the high-speed vehicles in order to get rid of restrictions of the slow vehicle, or implement some driving purpose, such as enter or exit ramp and
implementation lane changing, thereby obtaining the maximum driving satisfaction or achieve the desired driving target.

Lane-changing driving behaviors are divided into judgmental lane change (discretionary lane changing) and mandatory lane change (mandatory lane changing) according to the characteristics of the driving state of the vehicle lane-change. The former occurs mainly on the basic freeway traffic smooth segments, and it belongs to the selective operation behavior and the driving operation of dispensable; the latter occurs mainly in the ramp entrances, interchange weaving area, upstream segment of the incident, and it is compulsory operating behavior which is indispensable in a driving operation. Figure 8 shows the general pattern of lane changes.

5.2 Modeling technology ideas

Simplify the process of lane-changing for continuous reverse circle curve geometrical description model, and select a vehicle skid limit as the circular curve security conditions, then gain the skid the critical curve radius in vehicle operating speed while lane-changing, thereby defining the critical vehicle lane-changing safe state. At the same time, the security constraints based on the model of the car-following increase fog driving reaction lag time parameters and lane-changing trajectory model, then construct the vehicles lane-changing security model. Figure 9 shows the lane-changing trajectory description model.

5.3 Lane-changing process description

The driver implement the following three operations in the vehicle lane-changing process: 1) the steering wheel to the rotation direction of the target lane, and the vehicle away from the current lane; 2) steering wheel the opposite direction rotation to ensure that the vehicle does not out off target lane; 3) steering wheel adjust angle little to ensure vehicle in the target lane-changing lanes and driving stability. Where the operations 1) and 2) the greatest impact on the vehicle lane-changing in driving safety. Based on the characteristics of the running
trajectory of the vehicle lane-changing, and simplify the trajectory for continuous reverse radius circular curve, the minimum turning radius circular curve speed limit for vehicles changing lanes limit minimum radius in this condition. Changing the lane of the actual vehicle there are the following two situations: the first situation is the actual curve radius of the vehicle changing lanes minimum radius smaller than the limit, then the vehicle will cause an accident skidding; and the second situation is the effective circle of the vehicle to change the lane the radius of the curve is greater than the minimum radius of the limit, then the vehicle will implementation lane-changing behavior safety. It shows that the continuous reverse circular curve driving trajectory can characterize the criticality safety trajectory characteristics of the vehicle lane-changing driving.

5.4 Lane-changing model construction

The basic assumptions of the model are following: 1) At the beginning of the vehicle lane-changing behavior, the vehicle do uniform circular motion around the center of the circle O₁ (radius R₁); after passing lane dividing line vehicles around the center of the circle the O₂ (radius R₂) do uniform circular motion; 2) At the beginning and the end of the vehicles lane-changing operation, the speed direction of the vehicle parallel to the road forward direction; 3) The vehicle speed change in direction while the vehicle speed value maintain a constant in the lane-changing process; 4) Continuous reverse the radius of the circular curve is equal in value.

Assume that the radius of the curve of the two circles around the reverse curve as R₁ and R₂ on the vehicle in both directions of rotation during the transverse displacement \( \Delta Y₁ \) and longitudinal displacement \( \Delta X₁ \). It is known from geometric characteristics relationship of the circular curve that between the central angle corresponding to the first circular curve is \( \frac{\Delta Y₁}{R₁} \) and the circular curve length is \( \frac{\Delta Y₁}{\arccos \left( \frac{R₂}{R₁} \right)} \).

Suppose the vehicle n do uniform circular motion around the center of the circle O₁, and the speed of the vehicle is approximated to the circumferential velocity \( \bar{V} \), that is \( V_n \approx \bar{V} \); then travel time of the vehicle n in continuous reverse circular curve is \( h₁ \):

\[
h₁ = \frac{7.2R₁}{\bar{V}} \arccos \left( \frac{R₂ - \Delta Y₁}{R₁} \right)
\] (8)

Where \( \bar{V} \) represents the speed of the vehicle n, km/h; other signification of the symbols are same as above. It is known from above reason and model that the lane-changing speed of the vehicle should be less than the speed the vehicle anti-slip critical, otherwise and the risk of skidding will take place while the vehicle operating lane change, causing the vehicle accident. Therefore, the relationship between the two characteristic speeds is that the latter contains the former.

Considering the characteristics of the vehicle width and the lane width, the longitudinal displacement should not exceed the width of current lane and target lane, the longitudinal displacement \( \Delta Y₂ \) while one time lane-changing should not exceed 0.75 times the width of the lane, \( \Delta Y₂ \leq 0.75W \). The constraints shows that longitudinal displacement of the two concentric circles of vehicle 1.5 times lane width, in this constraint it will not turn into the adjacent lane or collision with the fixture. Therefore, while the vehicle n change lane \( \lambda \) times, in the continuous reverse shortest travel time \( h_{max}(n) \) on the circular curve is following:

\[
h_{max}(n) = h₁(n) + h₂(n) = 2h₁ \left( \frac{7.2R₁}{\bar{V}} \arccos \left( \frac{R₂ - 0.75\lambda W}{R₁} \right) \right)
\] (9)
5.5 The lane-changing numerical simulation analysis

Take the freeway (standard lane width 3.75m) for example, spreadsheet situation of different number of lane-changing.

<table>
<thead>
<tr>
<th>Weather</th>
<th>Lane-changing one time</th>
<th>Lane-changing two times</th>
<th>Lane-changing three times</th>
<th>Weather</th>
<th>Lane-changing one time</th>
<th>Lane-changing two times</th>
<th>Lane-changing three times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny</td>
<td>2.35 s</td>
<td>3.35 s</td>
<td>4.14 s</td>
<td>Ice</td>
<td>3.58 s</td>
<td>5.08 s</td>
<td>6.24 s</td>
</tr>
<tr>
<td>Rainy</td>
<td>2.69 s</td>
<td>3.83 s</td>
<td>4.72 s</td>
<td>Snowy</td>
<td>2.69 s</td>
<td>3.83 s</td>
<td>4.72 s</td>
</tr>
</tbody>
</table>

Note: According to the principle of maximizing safety under different weather conditions, road horizontal and vertical attachment coefficient to take minimum value.

The numerical spreadsheet results shows that in different weather conditions, the required longest travel time of the vehicle is in ice weather conditions, and it is about 3.5s; and the difference lane-change time between sunny and rainy (snowy) day about 0.3s, but the difference lane-change time between sunny and ice day is about 1.2s; and the vehicle for each additional change lanes, travel time increases about 1.0 s. It shows that the headway of vehicle lane-changing is greater with the reduction of road adhesion coefficient; and more times of the lane-changing, the longer time the vehicle changing lanes required.

5.6 Collision avoidance model

When the headway of the vehicle no target lane meet turning limits, it can only guarantee the vehicle n will not skidding or rollover, but cannot guarantee that the vehicle n will not collide with the front or following vehicle on the target lane. Therefore, the vehicle n should meet the horizontal constraints. At the same time, the vehicle n which attempt to change lane should not collide with the front or following vehicle on the target lane, and the security constraint conditions are following:

\[ h_{n} \leq \frac{V_{n}^2}{70.56(\mu + \ell)} + \frac{V_{n}(\tau + \tau_{r})}{V_{n}} + \frac{3.6L}{V_{n}} \]  \hspace{1cm} (10)

\[ h_{n-1} \geq \frac{V_{n}^2}{70.56(\mu + \ell)} + \frac{V_{n}(\tau + \tau_{r})}{V_{n}} + \frac{3.6L}{V_{n}} \]  \hspace{1cm} (11)

Where \( h_{n} \) represents the safety headway between the vehicle n and the lane-changing vehicle n, \( s \); \( V_{n} \) represents the speed of the vehicle n which attempt to change lane, km/h; \( V_{n-1} \) represents the speed of the vehicle n-1 on the target lane, km/h; \( \mu \) represents pavement vertical adhesion coefficient; \( \ell \) represents routes longitudinal slope (uphill for"+", downhill for"-"); \( L \) represents the safe stopping distance, and values 11m; \( \tau \) represents the driver's reaction time which take value of 0.5~1.5s.

5.7 Lane-changing security model

In the actual traffic flow, the reaction for motion state of the vehicle ahead is more sensitive than the vehicle following. It is to say that the driver of the vehicle n is more sensitive to the front vehicle n-1 than the following
vehicle $n+1$. Therefore, considering the road capacity and operational safety, select the smallest headway model of the vehicle $n$ and the front vehicle $n-1$ as the security model of the vehicle lane-changing are following:

$$\bar{h}_n(n) = \frac{V_{i}^2}{70.56(\mu_s + \lambda)} \cdot \frac{V_{i}^2}{V_{L}} + \frac{3.6L}{V_{i}} + \frac{7.2R_i}{V_{i}} \cdot \arccos \left( \frac{R_i - 0.75AV_l}{R_i} \right)$$ (12)

Where $\bar{h}_n(n)$ represent the minimum headway on the target lane that vehicle $n$ required when change lanes, $s$. It is known according to the assumptions and construction of the model that vehicle lane change trajectory simplified continuous reverse circular curve geometrical description of the model, as the transition curve radius a middle parameters of the security critical state, and select the vehicle skid ultimate in speed limit as the safety constraints conditions in order to achieve contact with the unification of the weather and the running state of the vehicle.

6 Summary and conclusions

There are few traffic models to study the effects rear-end and lane-changing collisions avoidance theory of the multi-lane freeway in disaster weather. In this paper, we took field traffic investigations in multi-lane freeway, and based on the classic car-following safety driving theory and consider the characteristics of visibility and impact of the adhesion coefficient in disaster weather events such as fog, snow, ice, establish car-following state security constraints and driving lag reaction model in fog.

Consider the impact of disaster weather on the pavement and visibility, establish criticality safety status of the vehicle change lanes proposed based on the characteristics of the trajectory of the vehicle change lanes based on the geometric description of continuous reverse circular curve model, analyze the lane-changing the required longest travel time of the vehicle in ice weather conditions according to numerical simulation and construct security model of the vehicle lane-changing and collision avoidance model.

The collisions avoidance models show that the safety-based approaching behavioral models could be used to analyze driver’s driving behavior for driving support and to reveal the essence of traffic flow characteristics at the microscopic level. The multi-lane freeway traffic safety research is still penurious, and the research required in-depth about multi-lane freeway such as safety and operations management in disaster weather and emergency events conditions. In this paper, the collision about car-following behavior and lane-changing behavior on multi-lane freeway in disaster weather studied, more theoretical research should conduct in-depth to solve the problem, such as car-following patient time, safe car-following distance, the perceptual threshold, lane-changing trajectory and driver behavior, and study the theoretical model which describe the multi-lane freeway traffic flow characteristics accurately to provides a theoretical basis for the safe design and operation and management of multi-lane freeway.

References


