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A Lane Change Model with the Consideration of Car Following Behavior

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Abstract

Lane change model is a hot issue of microscopic traffic simulation and active safety. Among current studies, most of lane change models based on vehicle kinematics hypothesize that when the vehicle of adjacent lane changes lane, the following vehicle of target lane keeps uniform motion. However, this hypothesis does not match with the real lane change scenario. In the paper we put forward a lane change model with the consideration of car following behaviour, and focus on kinematic behaviour of the lane-changing vehicle in the process of accelerated lane change. We construct a lane change scenario and derive a reasonable lane change model, and finally testify the model performance by MATLAB simulation. The results show the new lane change model is simple and reasonable, which can fit with the real lane change scenario. In addition, the proposed model can also provide some reference lane change algorithms for Intelligent Vehicle.

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Keywords:lane change model;kinematics;car following;simulation

1.Introduction

The lane change behaviour is the most common driving behaviour. Driver's misjudgement or driving skills of different levels during the lane changing is likely to cause traffic accidents, and accidents caused by lane changing accounting for 6% of the total traffic accidents and causing traffic delay time is more than 10% of total delay time by traffic accidents. According to statistics, the traffic accidents caused by the drivers' misjudgement account for about 75% (PENG Jinshuan, 2011). Therefore, the driver's judgment decision is important for making a safe lane change.

Usually, there exist two perspectives to study lane change model. One emphasizes on process analysis including lane changing demand and the prediction of inter-vehicle gap, such as : MRS(ZHANG Yunlong,1998),NETSIM(MEHOODA,2003),FRESIM(MEHOODA,2003),MITSIM (YANG Qi,1996) and the other emphasizes on kinematic property in the process of lane change , such as reference(XU Lunhui,2011)and reference(Jin Lisheng,2009),which aiming at the latter situation, the model analysis hypothesizes all the vehicles run at constant speed except the lane-changing vehicle. According to driver usual behavior, if there occurs a vehicle want to run at front of his own vehicle and he permits this behavior, then he will speed down to ensure safety with both itself and the vehicle who want to change lane. As a result, the hypothesis, following vehicle of the target lane drives at constant speed, does not consort with the real situation. Therefore, this paper put forward a lane change model with the consideration of car following behaviour, focusing on kinematic behaviour of the lane-changing vehicle in the process of accelerated lane change, constructing lane change scenario, deriving a reasonable lane change model and finally examining the model by MATLAB simulation test.

2.Structure of lane change scenario

Vehicle continuous lane change can be considered to be the result of the superposition of the two-lane lane change several times. Therefore, this paper only analysis the two-lane lane change model. The complete lane change scenario is shown in Figure 1.

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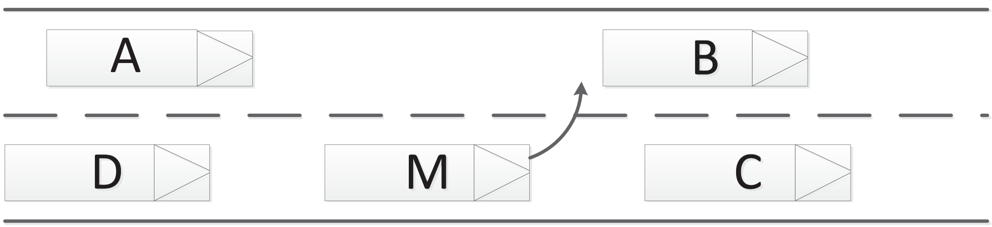

Figure1. The complete lane change scenario

In Figure 1,vehicle M is the vehicle who want to make a lane change, vehicle C and vehicle D are the leading and following vehicles in the same lane with vehicle M respectively, vehicle B and vehicle A are the leading and following vehicles respectively in the target lane. Vehicle M is the only Intelligent Vehicle equipped with vehicle-mounted sensors and others are all social vehicles without mounted sensors. Vehicle M switches to the target lane between vehicle A and vehicle B from its own lane between vehicle C and vehicle D. Reference (A EI Hajjaji, 2001) points out vehicle D hardly has influence on vehicle M in the lane change compared with vehicle A, band vehicle C. Therefore, this paper mainly focuses on the influence of vehicle A, vehicle B and vehicle C upon vehicle M in the process of accelerated lane change (that is from low-speed lane to high-speed lane to make a lane change).

3.Lane change model construction

This model is based on the analysis of kinematics. The model hypotheses are described as follows:

1) In the process of vehicle M making a lane change, vehicle M moves at a constant positive acceleration and vehicle A moves at a constant negative acceleration. Vehicle C and vehicle B both maintain uniform motion.

2) The change of transverse velocity does not affect the change in the longitudinal velocity in the process of vehicle M making a lane change.

The survey data show that 81.3% of the driver on the highway in the lane changing process has acceleration and deceleration behaviour (J.Mar,2005).Accelerated lane change time generally lasts 3~5 seconds, so that we can define vehicle M moves at a constant positive acceleration, namely the first hypothesis is reasonable. The vertical angle of vehicle in high-speed lane changing is small and the suggestion in the reference (Jose L Bascunana, 1995) is 5 rad. Therefore, we only consider the longitudinal velocity in the lane changing process, that is, the second hypothesis is also reasonable.

Usually, the lane change process can be divided into two parts. The first part is the process of accelerated lane change, the second part is the lane-changing vehicle moving at the target lane. Considering from the real lane changing process, when the lane-changing vehicle arrives at the target lane, the drivers adjust the speed to make sure its safety with the leading vehicles of the target lane. At the same time, the following vehicle rearranges speed to be safe with the lane-changing vehicle. Consequently, in order to ensure the second part implements safely, we only to make sure the lane-changing vehicle and the leading vehicle of the target lane keep an appropriate distance. In summary, this paper mainly focuses on the first part.

We can divide the process of accelerated lane change into the following three steps:

1) The step 1 of accelerated lane change: determine the distance between vehicle M and vehicle C to ensure the lane change safe.

2) The step 2 of accelerated lane change: whether the vehicle M can change lane from the space between vehicle A and vehicle B mainly depends on the distance relationship with vehicle A.

3) The step 3 of accelerated lane change: the safe distance between vehicle B should be considered when vehicle M arrives at the target lane.

Vehicle M can only make a lane change when all the three steps are carried out. After vehicle M arrives at the target lane, vehicle M will adjust its speed to guarantee the safety with vehicle B. Vehicle A accordingly adjust its speed to ensure the safety with vehicle M.

3.1. Model building for step 1 of accelerated lane change

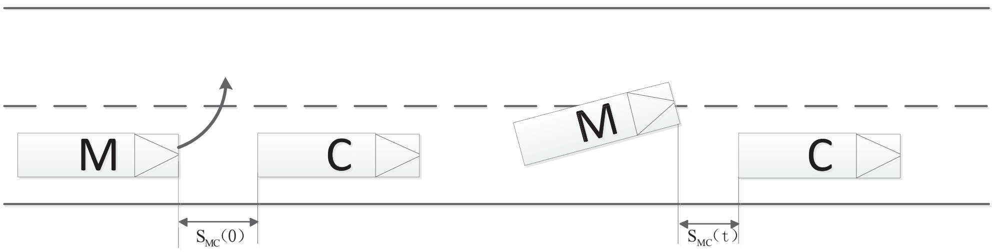

Figure2. Schematic diagram for step 1of accelerated lane change

Where: $S_{MC}(0)$ denotes the distance between vehicle M and vehicle C at the start moment of lane changing;

$S_{MC}(t)$ denotes the distance between vehicle M and vehicle C at any moment of lane changing.

1) Determine the longitudinal acceleration of vehicle M

In the process of accelerated lane change, vehicle M moves at a constant positive acceleration. The acceleration of vehicle M can be computed as:

$$a_M = \frac{V_e - V_0}{t}, t \in [t_0, t_a] \tag{1}$$

In formulation (1), V_e denotes the desired speed of vehicle M, V_0 denotes the initial speed of vehicle M, t_0 denotes the start moment of accelerated lane change and t_a denotes the end moment of accelerated lane change.

2) The ensurance of the safety between vehicle M and vehicle C in the process of vehicle M making an accelerated lane change

The displacement of vehicle M at any time t can be computed as:

$$S_M = V_0 t + \frac{1}{2} a_M t^2, t \in [t_0, t_a] \tag{2}$$

The displacement of vehicle C at any time t can be computed as:

$$S_C = V_C t, t \in [t_0, t_a] \tag{3}$$

Where V_C denotes the speed of vehicle C.

Therefore, we obtain the distance between vehicle M and vehicle C at any moment in $[t_0, t_a]$ as follows:

$$S_{MC}(t) = S_C - S_M + S_{MC}(0) \quad, t \in [t_0, t_a] \tag{4}$$

To make sure that vehicle M does not make a collision with vehicle C in the time period $[t_0, t_a]$, the condition $S_{MC}(t) \geq 0$ should be satisfied. There must have existed a moment, that is $t_c \in [t_0, t_a]$, making the value of $S_{MC}(t)$ to achieve the maximum. Just satisfy the condition, $S_{MC}(t_c) \geq 0$, can we ensure the vehicle M does not make a collision with vehicle C in the time period $[t_0, t_a]$.

3.2. Model building for step 2 of accelerated lane change

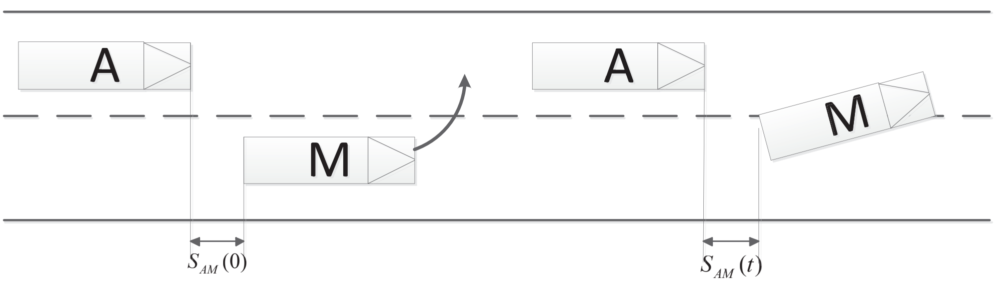

Figure3. Schematic diagram for step 2 one of accelerated lane change

Where: $S_{AM}(0)$ denotes the distance between vehicle A and vehicle M at the start moment of lane changing;

$S_{AM}(t)$ denotes the distance between vehicle A and vehicle M at any moment of lane changing.

1) Determine the condition satisfied by $S_{AM}(t)$

When the vehicle M has the lane-changing intention and is allowed by vehicle A, the vehicle A should give responds to this situation, that is to say, moving at a constant negative acceleration to ensure the safety of vehicle A and vehicle M in the process of vehicle M making a lane change.

Therefore, the displacement of vehicle A in the time period $[t_0, t_a]$ can be computed as:

$$S_A = V_A t - \frac{1}{2} a_A t^2, t \in [t_0, t_a] \tag{5}$$

Where V_A denotes the initial speed of vehicle A and a_A denotes the acceleration of vehicle A in the lane changing of vehicle M process.

Some research has considered the safe distance (Wang Jianqiang, 2005).We can draw on the experience of the alarm algorithm, which is expressed as:

$$x_{wr} = v_c \cdot t_{hw} + x_{off}$$

In this formulation, x_{wr} denotes the alarm distance that driver feels dangerous, v_c denotes the speed of the vehicle, t_{hw} denotes the time headway, whose value can be set from 1 to 2 seconds to reflect the driver's subjective judgment on the highway, and x_{off} denotes the appropriate stopping distance, which can be set at 10 meters.

Then we obtain the following expression:

$$S_{AM}(t) = (V_A - a_A t) \cdot t_{hw} + x_{off}, t \in [t_0, t_a] \tag{6}$$

2) Determine the condition satisfied by $S_{AM}(0)$

In the process of vehicle M carrying out the accelerated lane change, we certainly hope vehicle M does not make a collision with vehicle A. Therefore, we consider the worst situation and obtain the expression in theory as follows:

$$S'_{AM}(0) = S_A - S_M + S_{AM}(t_c) \tag{7}$$

Where $S'_{AM}(0)$ denotes the initial distance between vehicle A and vehicle M in theory and $S_{AM}(t_c)$ denotes the maximum of formulation (6), which works out at the point $t_c \in [t_0, t_a]$.

As a result, to ensure vehicle M does not make a collision with vehicle A, the condition should be established as follows:

$$S_{AM}(0) \geq S'_{AM}(0) \tag{8}$$

3.3. Model building for step 3 of accelerated lane change

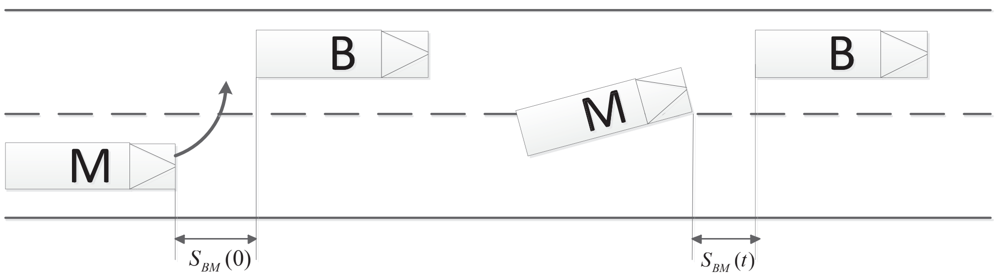

Figure4. Schematic diagram for step 3 of accelerated lane change

Where: $S_{BM}(0)$ denotes the distance between vehicle B and vehicle M at the start moment of lane changing;

$S_{BM}(t)$ denotes the distance between vehicle B and vehicle M at any moment of lane changing.

1) Determine the condition satisfied by $S_{BM}(t)$

In the process of vehicle M changing its lane, the driver's attention focuses on the vehicle B, the leading vehicle on the target lane. This process can be identified that vehicle M follows the tracks of the vehicle B. The safe distance model based on time headway is regard as the basic model put forward by former study (Tim van Dijck, 2005) .The model is simple and practical, which is also widely used among the simulation software, and its expression is:

$$\begin{cases} d_{ref} = c_1 + c_2 \cdot v(t) \\ d_{err} = d_{ra} - d_{ref} \\ a_{ref\_d} = c_d \cdot d_{err} + c_p (V_B(t) - V_M(t)) \end{cases} \tag{9}$$

The parameters are described in Table1.

Table 1. The description of parameters in formulation numbered by (9)

Parameters	Description
d_{ref}	Desired distance headway as a function of speed
c_1, c_2	Constant(set at 3,0.25)
$v(t)$	Current speed
d_{err}	Deviation from desired
d_{ra}	Distance measured by sensors such as radar on current time
a_{ref_d}	Driver's desired acceleration for car following
c_d	Constant factor for distance deviation (set at 0.3)
c_p	Constant factor for speed deviation front vehicle (set at 1.5)
$V_B(t)$	The speed of vehicle B on current time
$V_M(t)$	The speed of vehicle M on current time

In the process of vehicle M making an accelerated lane change, the most dangerous moment for the collision with vehicle B is the end moment of lane change. Therefore, we hope that vehicle M keeps the safe distance with vehicle B at the end moment of lane change, which is expressed as follows:

$$a_M = a_{ref\_d} \tag{10}$$

$$S_{BM}(t_a) = d_{ref} = c_1 + c_2 \cdot V_e \tag{11}$$

2) Determine the condition satisfied by $S_{BM}(0)$

We obtain the condition satisfied by $S'_{BM}(0)$, the initial distance between vehicle B and vehicle M in theory. Then combine with formulation (9), formulation (10) and formulation (11).We obtain the following expression:

$$S'_{BM}(0) = \frac{a_M - c_p(V_B - V_e)}{c_d} + S_{BM}(t_a) \tag{12}$$

In order to ensure the vehicle M keeps safe distance with vehicle at the end moment of lane change, the following expression should be satisfied:

$$\mathrm{S_{BM}}(0) \geq \mathrm{S'_{BM}}(0) \tag{13}$$

4. Simulation test

1)The workflow of vehicle M making a lane change decision

In conclusion, the workflow of vehicle M making a lane change decision is shown in Figure 5.

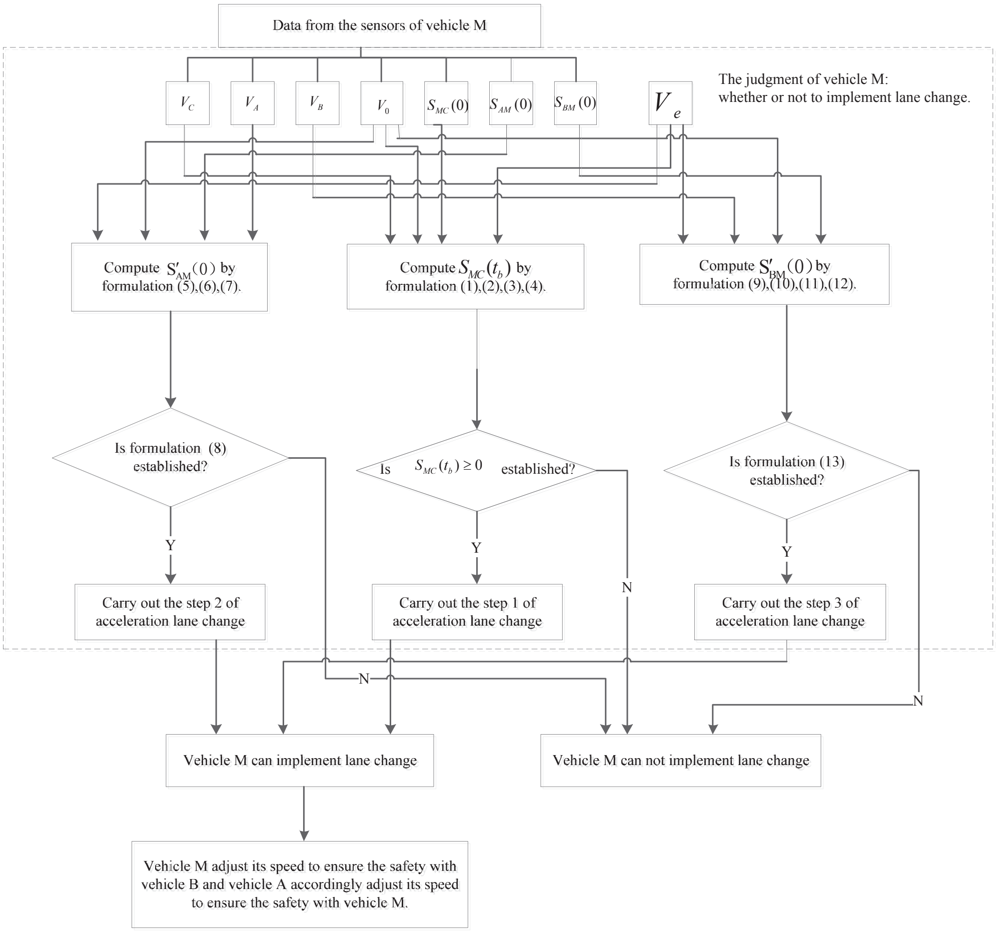

Figure5.The flowchart of vehicle M making lane change decision

2) Simulation experiment using MATLAB

The simulation parameters can be set shown in Table 2.

Table 2.The simulation parameters and their value

Parameters	Value
V_0	$22\ m/s$
V_e	$25\ m/s$
V_C	$20\ m/s$
V_A	$23\ m/s$
V_B	$25\ m/s$
$S_{MC}(0)$	$26\ m$
$S_{AM}(0)$	$60\ m$
$S_{BM}(0)$	$60\ m$

Using MATLAB, The longitudinal displacement variation curve of vehicle M, the speed variation of vehicle M, the step 1 variation of accelerated lane change curve, the step 2 variation of accelerated lane change curve, the step 3 variation of accelerated lane change curve are as shown in Figure 6-10 respectively.

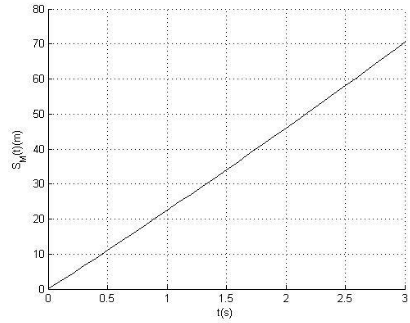

Figure 6. Longitudinal displacement variation curve of vehicle M

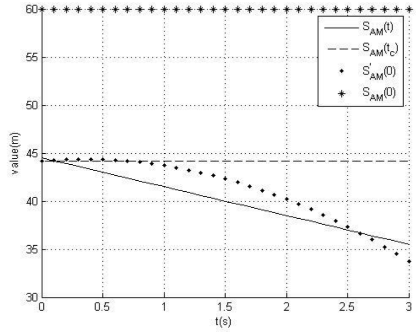

Figure 9. The step 2 variation of accelerated lane change curve

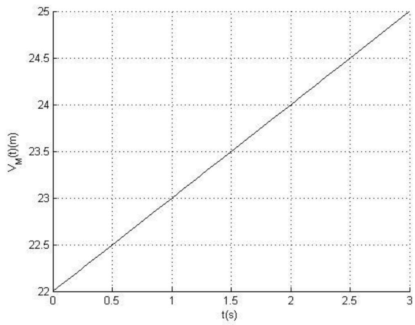

Figure 7. The speed variation of vehicle M

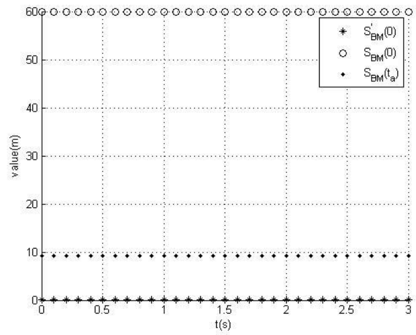

Figure 10.The step 3 variation of accelerated lane change curve

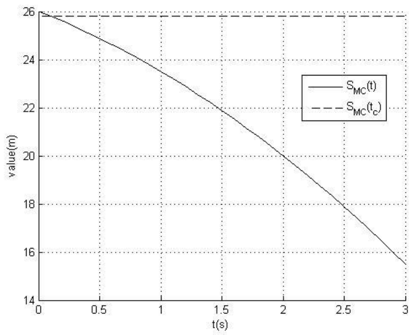

Figure 8. The step 1 variation of accelerated lane change curve

It can be found that the vehicle M moves at a constant positive acceleration from Figure 6 and Figure 7.

We note that $S_{MC}(t_c) \geq 0$ from Figure 8, that is to say, vehicle M will not make a collision with vehicle C in the time period $[t_0, t_a]$ and the step 1 of accelerated lane change can be carried out. Similarly, $S_{AM}(0) > S'_{AM}(0)$ can be seen from Figure 9 and formulation (8) is established. Consequently, vehicle M will not make a collision with vehicle A in the time period $[t_0, t_a]$ and the step 2 of accelerated lane change can be implemented. In addition, $\mathrm{S_{BM}}(0) > \mathrm{S'_{BM}}(0)$ can be drawn from Figure 10 and formulation (13) is established. It shows that vehicle M will not make a collision with vehicle B in the time period $[t_0, t_a]$ and the step 3 of accelerated lane change can be executed. As a conclusion, the lane change of vehicle M can be put into effect.

From Figure 9, it is noteworthy that $S_{AM}(0)$ is much bigger than $S'_{AM}(0)$ .This phenomenon indicates that the initial distance between vehicle M and vehicle A can be closer (not less than $S'_{AM}(0)$) to make a safe lane change. Likewise, we obtain that $S_{BM}(0)$ is much bigger than $S'_{BM}(0)$ drawn from Figure 10. Initial distance between vehicle M and vehicle B can also be closer (not less than $S'_{BM}(0)$) to ensure a safe lane change.

The three accelerated lane change steps are in smooth process, and no fluctuation. Besides, the comfortability and response of speed are both better and in accordance of driver lane change behavior in practice.

5. Conclusion

Considering the car following behavior, and basing on the real lane change scenario and mainly focusing on kinematic behaviour of the lane-changing vehicle in the process of accelerated lane change, this study constructs a lane change model with the consideration of car following behavior. The simulation results indicate the process of accelerated lane change accomplishes safely in the properly-chosen time limitation and the whole lane change process can be finished through smooth speed variation, which guarantees the comfortability of driving. This new model gives some reference upon the practicality of lane change algorithms for Intelligent Vehicle.

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