Research on Safety Lane Change Model of Driver Assistant System on Highway

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Abstract- **To solve those traffic accidents during conscious lane change of vehicles on highway under dangerous conditions, a new safety lane change model is established on the basis of the lane departure warning system which Jilin University has developed. This model is studied under a typical scenario on highway, and also considered with the actual driver behavior that most vehicles always accelerate during lane changing process. Simulation software is developed to testify the model performance based on Matlab7.0. The results show that the new lane change model can offer certain technical foundation for actualization of safety lane change system of vehicle assistant driving on highway.**

Keywords: **Lane change; driver assistant system; simulation**

I. INTRODUCTION

According to statistics, human error account almost for seventy five percent of total traffic accidents. The proportion of traffic accidents caused by lane change is about four to ten percent of the total traffic accidents. Although, this value is not high, but the delay time it caused accounts for ten percent of the total time caused by all traffic accidents [1], and it results in huge economic losses for the society. If the driver could be able to obtain accurate information about vehicles around and to be reminded effectively before risk emerged in good time, the occurrence frequency of such traffic accidents could be reduced obviously. Vehicle lane change assistant system is an effective means of guaranteeing a vehicle changing lane safely. Some developed countries, such as the United States, Japan and the EU, have already made a few achievements and begin to put into service partly [2, 3]. Recently, some Chinese Universities (e.g., Tsinghua University, Jilin University) and scientific institutions have also made research on Driver Assistant Systems, such as vehicle forward collision avoidance system[4,5] etc. But, few researches have been made on Lane Changing System in China. This paper gives some technical support for the establishment of safety lane change system of vehicle assistant driving on highway through the research of safety lane change model of vehicles in a specific scenario based on the study of the lane departure warning system, which we have developed before and aims at solving those traffic accidents caused by the vehicle unconsciously leaves its normal running lane [6].

The structure of this paper is as follows. Section II introduces the lane change scenario that the paper researched; Section III presents the establishment of the lane change model. In section IV, some simulation results are introduced. The last section makes some conclusions about the paper.

II. SCENARIO FOR LANE CHANGE MODEL RESEARCH

Safety lane change of vehicle is one of the most important components of vehicle safety assistant driving. Until now, the study of host vehicle, the preceding vehicle in current driveway, and the preceding vehicle driving in the target lane has already been researched for many years, and a few products could be found on the market such as safe range keeping system, ACC, etc [1,7]. Actually, because of blind spot and driver's distraction, one can't perceive vehicles or pedestrians around, and this may trigger off traffic accident when drivers performing lane change strategy. In the process of lane change, the following vehicle in the target lane is a more danger factor than the preceding vehicles running ahead of host vehicle in current lane or target lane [1.8].

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Consequently, this paper will put more efforts into the study of microcosmic safety lane change model system combined by host vehicle and the following vehicle in the target lane. As for the preceding vehicle L_o in current lane and the preceding vehicle Ld in the target lane, a typical model now used based on safety time space tracking model is adopted to ascertain their relation with host vehicle M. The scenario that this paper considered can be seen in figure 1.

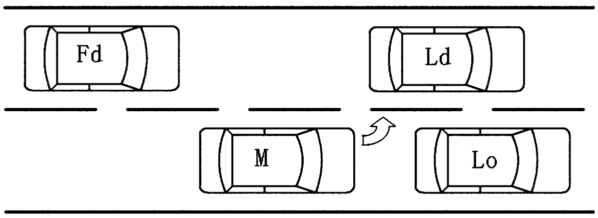

Fig.1 Research scenario of vehicle lane change on highway

III. Lane Change Model Establishment

A. Lane Changing Process Segmentation

Recent research shows that about 81.3 percent of drivers would perform operations of acceleration or deceleration in the process of lane change[9], and in the initial phase, most drivers always show accelerate action. So in this paper we consider that the vehicle runs into an adjacent lane with constant acceleration during initial lane change phase and then adjusts self-velocity in the target lane. These can guarantee safe space between two moving vehicles. The lane changing time segmentation is shown as figure 2.

Fig.2 Time segmentation of lane changing process

In figure 2, t_0 is the time when a vehicle begins to change lane; t_{lat} is the time vehicle M runs into the target lane by acceleration; t_c means the time when vehicle M arrives at collision point with vehicle Fd ; T means the time when vehicle M completes the whole lane change.

The relative position of vehicle M and Fd at initial time and at any time during lane change is shown in figure 3.

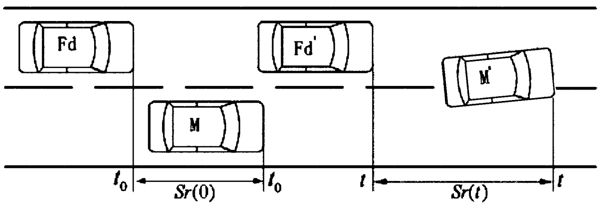

Fig.3 Sketch map of lane changing process

In figure 3, t denotes any time of lane change; $Sr(0)$ is the initial distance between M and Fd ; $Sr(t)$ is the distance between M and Fd at any time during lane change.

Because of high speed in the process of lane change and small longitudinal angle of vehicle on highway (As some literatures suggest about five degree [3]), this paper neglects the influence on longitudinal speed by lateral acceleration, and only considers the influence of longitudinal acceleration.

B. Minimum safety Space Modeling When Lane Changing

The acceleration of vehicle M in accelerated phase can be shown as equation (1).

$$a_M = (v_{ref} - v_M(0)) / t_{lat}, \quad 0 \le t \le t_{lat} \tag{1}$$

Here, v_{ref} means the desired speed of vehicle $M, (v_{ref} \ge v_{Fd})$, and $v_M(0)$ means the initial speed of vehicle M .

Considering the passenger comfort, the acceleration a_M of host vehicle belongs to $(0m/s^2, 2m/s^2)$. [1].. Combine with figure 3, the expression of $Sr(t)$ can be described as equation (2).

$$Sr(t) = Sr(0) + \frac{1}{2} a_M t^2 + (v_M(0) - v_{Fd})t, \quad t \in [0, t_{lat}] \tag{2}$$

From figure 3, we know that vehicle M and Fd will not collide with each other in the process of lane change only if $Sr(t) \ge Lv$ is always ensured. Here, L_v is the length of vehicle M . So, we can get the following inequation (3) based on equation (2).

$$Sr(0) \ge (v_{Fd} - v_M(0))t - \frac{1}{2} a_M t^2 + Lv, \quad t \in [0, t_{lat}] \tag{3}$$

Here, $Sr(0)$ is the initial minimum safety space to ensure that vehicle M and Fd will not collide with each other. Analysis on inequation (3), we can get the following conclusions.

(1) $v_{Fd} - v_M(0) \le 0$, since vehicle M accelerates during initial lane change, only if $Sr(0) > Lv$, vehicle M will not collide with vehicle Fd.

(2) $v_{Fd} - v_M(0) > 0$, When vehicle M's speed up to v_{Fd}, and $t_c = (v_{Fd} - v_M(0))/a_M$, the distance of $Sr(t)$ will drop to minimum. So, the minimal distance of $Sr(0)$ can be shown as equation (4).

$$Sr(0)_{\min} = (v_{Fd} - v_M(0)) \cdot t_c - \frac{1}{2} a_M \cdot t_c^{\,2} + Lv \quad (4)$$

C. Minimum safety Space in Safe Tracking Phase Analysis

Host vehicle adjusts self-velocity to ensure the safe tracking space from time t_{lat} to time T. As mentioned above, there are rather popular achievements in safe tracking field [7]. In this paper, the model based on safe tracking head time distance is utilized directly [1, 5]. The expressions can be shown as equation (5), equation (6) and equation (7).

$$a_M(t) = k_1 \cdot D_{err}(t) + k_2 \cdot (v_{Ld}(t) - v_M(t)) \quad (5)$$

$$D_{err}(t) = D_{survey}(t) - D_{cr}(t) \quad (6)$$

$$D_{cr}(t) = c_1 \cdot v_M(t) + D_o \quad (7)$$

$$t \in [t_{lat}, \;\; T]$$

Here, k_1, k_2 means the constants (respectively 0.3,1.5), $D_{err}(t)$ means the deviation of current vehicle space relative to safe following space, $D_{survey}(t)$ means the space between two vehicles in current state, $D_{cr}(t)$ means safe following space, c_1 means head time distance (generally 1-2 second), and D_0 means safe parking space (Here, the paper choose 10 m).

According to above analysis, we can conclude that, for vehicle Fd and M, two vehicles will be in safe following phase after M moves into the target lane. So the space between two vehicles should be ensured longer than the minimum safe following space after vehicle M moves into target lane. So,

$$Sr(t_{lat}) \ge D_{cr}(t_{lat}) = c_1 \cdot v_{F_d}(t_{lat}) + D_o \quad (8)$$

D. Confirmation of Minimum safety Lane Change Space between Vehicle M and Fd.

As for the minimum safety space modeling in the acceleration phase of initial lane change, only normal condition is considered. Actually, because of the above minimum safe space with equation (3), two vehicles will still be able to collide with each other if vehicle M decelerates abruptly in real lane experiment or in the process of future employment. To ensure driving safety that the two vehicles will not collide when and after lane change, MSS (Minimum safety Space) between vehicle M and Fd in the entire process of lane change can be shown as equation (9) according to literature [9].

$$MSS = Sr(0)_{\min} + D_{cr}(t_{lat}) \quad (9)$$

IV. Simulation Test

To validate the established model, the lane change simulation software based on Matlab7.0 is developed. Because vehicle would be affected by many factors when changing lane, we take into account the influence of the preceding vehicle Ld in current lane and the preceding vehicle Lo in target lane to ensure that the model presented in this paper answers for actual driving on highway. For preceding vehicle, we only employ the following model based on safety head time space (As depicted before.) to guarantee safe space between vehicle M and Ld, also M and Lo, in the process of lane change.

Simulation parameters are as follows. Initial speed of M is 22 m/s and the desired speed of M is 25 m/s. Initial speed of Lo, Fd and Ld is about 20 m/s, 23 m/s and 25 m/s respectively. The initial distance between M and Lo is about 26 m and the initial distance between M and Ld is about 60 m, also the initial distance between M and Fd is also the same with 60 m.

The selection of lane change time has huge influences on the security of lane change model, as well as lane change on actual highway. Statistically data show that about three to five seconds is a proper time for the vehicle to accelerate and then change lane safely and smoothly. Also the data shows more time it takes, more risk increases [9]. Meanwhile, it's very difficult to estimate traffic safety. Until now, in this research filed, TTC (time to collision), which denotes the time needed for two vehicles to collide if they keep moving according to their current state, is a conventional estimation method. It is reported that 3 second is the most suitable time for TTC [10]. So the time t_{lat} to acceleration and lane change we set in this paper is 3s. Matlab simulation interface is shown as figure 4.

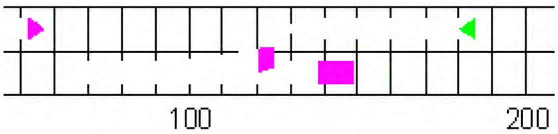

Fig.4 Simulation interface of lane change

In figure 4, means vehicle Fd , means vehicle M , means vehicle Lo , and means vehicle Ld .

From simulation, we can get lateral displacement changing curve of M , speed changing curve of M , longitudinal displacement changing curve between M and Lo , longitudinal displacement changing curve between M and Ld , longitudinal displacement changing curve between M and Fd . The simulation results are shown from figure 5 to figure 9.

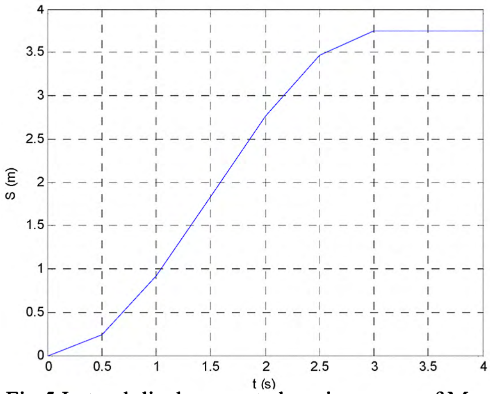

Fig.5 Lateral displacement changing curve of M

According to simulation results, we know that based on the established model of this paper, the vehicle accomplishes the lane change safely and successfully in 3 seconds, and the velocity doesn't change sharply. After lane change, the distance between M and Fd is 55.2 m , which fulfils the demand of the minimum space between two vehicles 51 m .

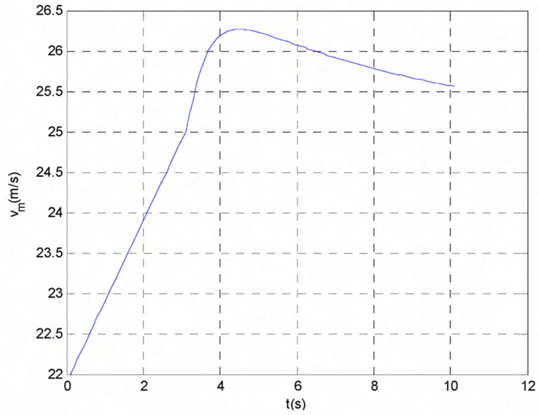

Fig.6 Speed changing curve of M

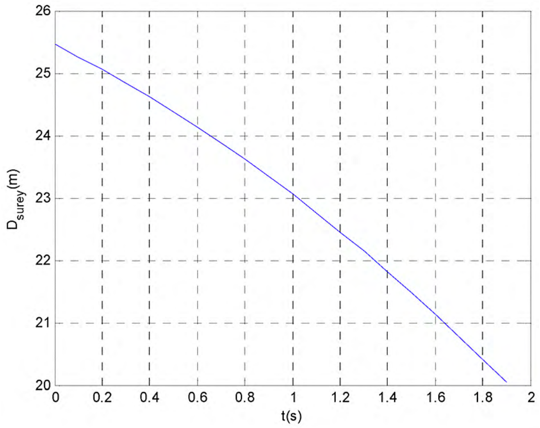

Fig.7 Longitudinal displacement changing curve between M and L_o

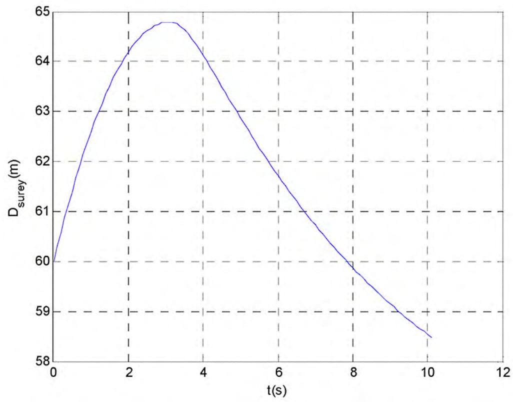

Fig.8 Longitudinal displacement changing curve between M and L_d

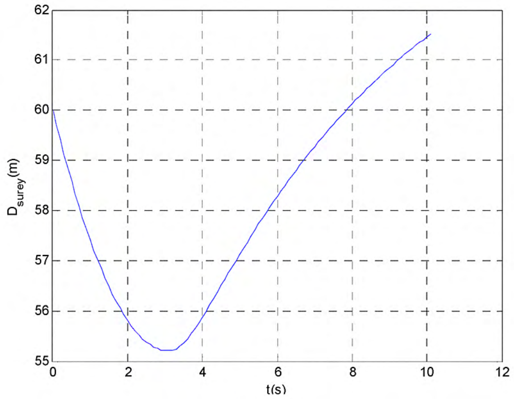

Fig.9 Longitudinal displacement changing curve between M and F_d

V. CONTRAST WITH TYPICAL MODEL

This paper contrasts the new method with the safety lane changing model developed by California University which is considered as the typical model [11]. Simulation parameters of California model the paper used are the same as above. Since the selection of minimum safety distance and lane changing time of 2 models are different (for example, lane changing time is 3 second for our model while the California typical model is about 10 seconds), the initial relative changing distance between M and Fd, M and Lo are different. Based on literature [11], we can get the speed changing curve of M , longitudinal displacement changing curve between M and Ld , longitudinal displacement changing curve between M and Fd , longitudinal displacement changing curve between M and Lo . The simulation results are shown from figure 10 to figure 13.

The simulation results show that the two models can fulfill lane changing safely and the proposed method of this paper has shorter safety distance. Also the proposed method has more quick response speed while the velocity of the vehicle does not change sharply which can fulfill the requirements of safety and passenger comfort. Host vehicle runs following the preceding vehicle Ld smoothly in the subsequent process after finish lane changing which also fit with the driver's behavior. The new model could be more adapt to the real lane changing of Chinese driver on highway.

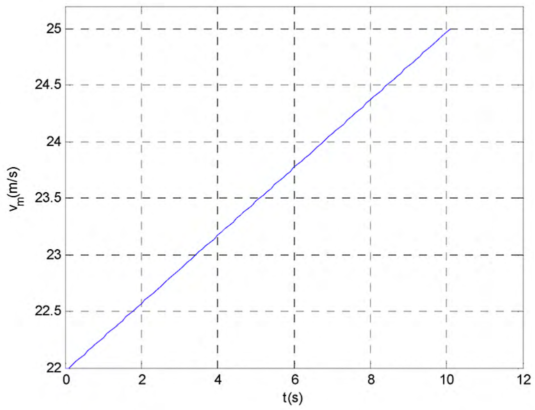

Fig.10 Speed displacement changing curve of M

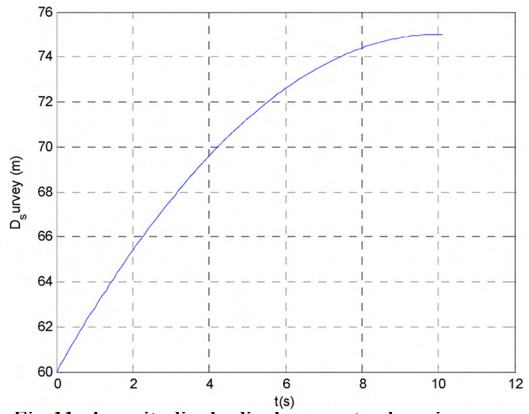

Fig.11 Longitudinal displacement changing curve between M and L_d

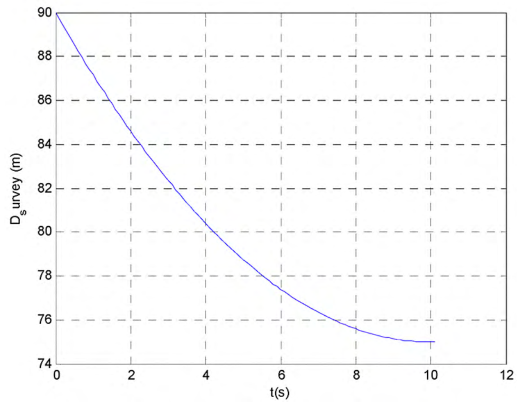

Fig.12 Longitudinal displacement changing curve between M and F_d

VI. CONCLUSIONS

Safety lane change model of driver assistant System on highway presented in this paper and the adopted method can provide a basis for judgment and decision making on the safety of lane changing and overtaking when driving on highway. Simulation results show that the vehicle can fulfill lane change safely and reliably within a reasonably given time, and the vehicle speed has no sharp change which can meet the needs of passenger comfort. So the model proposed in this paper can offer certain technical foundation for actualization of safety lane change system of driver assistant on highway.

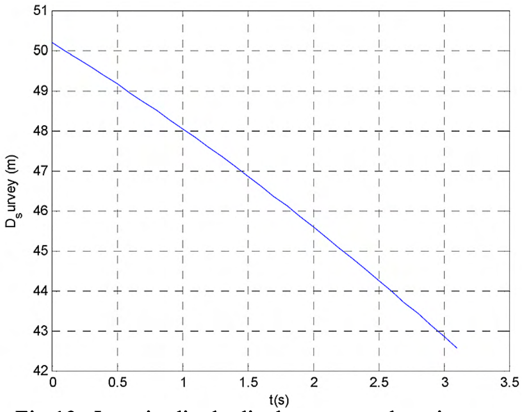

Fig.13 Longitudinal displacement changing curve between M and L_o

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