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Lane change warning threshold based on driver perception characteristics

Chang Wang, Qinyu Sun*, Rui Fu, Zhen Li, Qiong Zhang

Chang'an University, School of Automobile, Middle Section of Nan'er Huan Road, Xi'an, 710064, China

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ABSTRACT

Lane Change Warning system (LCW) is exploited to alleviate driver workload and improve the safety performance of lane changes. Depending on the secure threshold, the lane change warning system could transmit caution to drivers. Although the system possesses substantial benefits, it may perturb the conventional operating of the driver and affect driver judgment if the warning threshold does not conform to the driver perception of safety. Therefore, it is essential to establish an appropriate warning threshold to enhance the accuracy rate and acceptability of the lane change warning system. This research aims to identify the threshold that conforms to the driver perception of the ability to safely change lanes with a rear vehicle fast approaching. We propose a theoretical warning model of lane change based on a safe minimum distance and deceleration of the rear vehicle. For the purpose of acquiring the different safety levels of lane changes, 30 licensed drivers are recruited and we obtain the extreme moments represented by driver perception characteristics from a Front Extremity Test and a Rear Extremity Test implemented on the freeway. The required deceleration of the rear vehicle corresponding to the extreme time is calculated according to the proposed model. In light of discrepancies in the deceleration in these extremity experiments, we determine two levels of a hierarchical warning system. The purpose of the primary warning is to remind drivers of the existence of potentially dangerous vehicles and the second warning is used to warn the driver to stop changing lanes immediately. We use the signal detection theory to analyze the data. Ultimately, we confirm that the first deceleration threshold is $1.5\,m/s^2$ and the second deceleration threshold is $2.7\,m/s^2$. The findings provide the basis for the algorithm design of LCW and enhance the acceptability of the intelligent system.

1. Introduction

Lane Change Warning system (LCW) has developed progressively and has been popularized in vehicle active safety systems to improve the safety of lane changes and reduce the driver's operation load (Rahman et al., 2017; Maram and Azzedine, 2017; Parampreet and Rajeev, 2017; Jeong et al., 2015). LCW can help drivers monitor surrounding vehicles and may decrease the risk of potential conflicts by providing a warning of possible collisions, especially during the lane change of subject vehicle with a fast approaching rear vehicle in the target lane (Paul et al., 2016; Khan et al., 2014; Alonso et al., 2008). From a prior view of safety, the warning system should deliver the caution as soon as possible. Premature warnings, however, might cause drivers to misconstrue the necessity for caution or may even regard it as an inaccurate warning (Ruscio et al., 2017; Naujoks et al., 2016). In light of the interactive relationship between the LCW and different drivers, confirming the appropriate warning threshold of lane changes according to this diversity of driver perception characteristics is essential to project the alert criterion of LCW (Preuk et al., 2016; Van Der Laan et al., 1997).

The research on lane change warning system is primarily centered on the model of warning, the level of the warning system, and the warning parameters. Gipps (1986) established a decision-making model of lane change behavior on urban roads. The safe and feasible lane change behavior of the subject vehicle was determined by an algorithm that evaluated whether the required deceleration of the rear vehicle was greater than the acceptable deceleration (generally assumed to be $-4\,m/s^2$). Hossein Jula et al. (2000) constructed a minimum safe spacing (MSS) model to ensure the safety of lane changes on freeways. Hyunjin Park et al. (2018) proposed the lane change risk index (LCRI) for estimating crash risk during lane changes. Time to collision (TTC) could reflect the relative velocity and relative distance between a subject vehicle and a target vehicle. TTC has been widely used in the correlation analysis of lane change safety (Das et al., 2015; Taieb and Shinar, 2001). Plenty of warning criteria have determined TTC as the warning parameter and searched for the appropriate TTC threshold (Biondi et al., 2017; Li et al., 2015; Julian, 2014).

Driver subjective perception of lane change safety and the ambient

* Corresponding author.
E-mail addresses: wangchang@chd.edu.cn (C. Wang), sunqinyu@chd.edu.cn (Q. Sun), furui@chd.edu.cn (R. Fu), lizhen@chd.edu.cn (Z. Li), mingfangzhang@chd.edu.cn (Q. Zhang).

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conditions (such as relative velocity and relative distance) possess discrepancies. Therefore, a unitary warning threshold does not satisfy these different levels of risk perception during the lane change process. In recent years, researchers have pursued ways to improve the driver's acceptance of LCW by distinguishing the warning levels and confirming the optimal warning threshold (Oh et al., 2017; Kala and Warwick, 2015). A threshold of the lane change collision avoidance system was proposed by comparing data from driving simulator experiments and vehicle field tests (Smith et al., 2003). In view of the conflict occurrence time, Bascunana (1995) divided the warning system into three levels according to the potential time and the response time required by warning system. Suzanne et al. (2004) split the collision urgency of lane change into four phases: TTC > 5.5 s, 3.0s < TTC ≤ 5.5 s, TTC ≤ 3.0 s, and collision. Wakasugi (2005) conducted experiments on a freeway to research the relationship between the subject vehicle and a rear vehicle in the target lane during the lane change process. A theoretical analysis and vehicle field test determined 2.0 s (time required to avoid collision calculated in theory), 6.0 s (minimum for lane change implication time), and 10 s (maximum time to abrogate lane change operation) as the three disparate TTC thresholds for application in LCW. Hirst and Graham (1997) found that the TTC for drivers to distinguish between safe and unsafe lane change behavior was determined to be 4.0 s on the basis of a vehicle field test, but it could enhance inaccurate alarm rate. ISO 17387:2008 classified the different levels of TTC on the basis of the relative approach velocity between the subject vehicle and a target vehicle in the adjacent lanes. A relative approach velocity less than 10 m/s corresponded with a TTC threshold of 2.5 s, the relative approach velocity from 10 m/s to 15 m/s corresponded with a TTC threshold of 3.0 s, and the relative approach velocity from 15 m/s to 20 m/s corresponded with a TTC threshold of 3.5 s. The patent of LCW applied by BOSCH Company (Bordes, 2012) had formulated a warning algorithm according to a combination of the TTC threshold with the rear area division of a subject vehicle. The distance in adjacent lanes from 3.0 m to 25 m away from the rear bumper of the subject vehicle corresponded with the TTC threshold of 2.5 s, the distance from 25 m to 45 m away from the rear bumper corresponded with the TTC threshold of 3.0 s, and the distance from 45 m to 70 m away from the rear bumper corresponded with a TTC threshold of 3.5 s. Yong et al. (1995) classified lane change safety into three levels and identified TTC thresholds of 3.0 s and 5.5 s. From the above, abundant researches on lane change warning system have pursued ways to confirm suitable TTC threshold, however, the calculated TTC is easily interfered with the relative velocity and relative distance. For instance, when the relative velocity between subject vehicle and rear vehicle is small, the calculated TTC value is larger than the threshold. Without another safety strategy, the warning system may not alarm driver even the relative distance exceed the safe distance.

Research on driver awareness characteristics has a strategic significance for exploiting warning systems (Goodrich and Boer, 2000). Any alarm criterion that does not conform to driver characteristic will deviate from the principle of being driver oriented, and as a consequence, the practicability of the warning is challenged (Adell, 2010).At present, many scholars pay significant attention to studying the LCW algorithm. Research on confirming an applicable warning threshold is sparse. The discrepancy of lane change among drivers has not been considered adequately. Therefore, the acceptance of LCW is not high.

In the actual lane change process, it is possible to create situations in which the subject vehicle persists in changing lanes even though the rear vehicle in the target lane is fast approaching. This study was constructed to determine the lane change warning threshold for a fast approaching collision that conformed to driver perception characteristics. Combining the MSS model with Gipps's research, we proposed a theoretical warning model of lane change based on the safe minimum distance and deceleration of a rear vehicle. We implemented extremity tests of lane changes on a freeway to confirm the point at which the ability to change lanes safely deviated from driver subjective perception. Then we analyzed the deceleration of a rear vehicle at a time parallel to this point. Finally, we used signal detection theory (SDT) to determine different warning thresholds based on these diverse warning levels and different drivers.

2. Experiment

2.1. Participants

We recruited a total of 17 experienced drivers (15 male, 2 female) to participate in the experiment. The participants were between the ages of 27 and 48 years old, with an average age of 34.7 years. Their driving experience was between 3 years and 23 years, with a mean age of 8.4 years. Each of the participants enjoyed good health and had not experienced a severe traffic accident over the past 3 years. After the experiment, statistical analysis of the test data indicated that the data of two drivers appeared to have an obvious deviation. The paucity of proficient driving skills and the high degree of tension during the trial could explain this instability. Therefore, the valid data applied in this work came from the remaining 15 subjects.

2.2. Procedure

Because the lane change warning threshold studied in this paper is aimed at the process of lane changes with a fast approaching vehicle, we simulated the process of a quickly approaching rear vehicle in the target lane from far to near. For the purpose of acquiring the different safety levels of lane changes from 'a slight effect on rear vehicle' to 'an inevitable conflict with rear vehicle ', the experiment process was split into two categories: the first was referred to as the Front Extremity Test for lane change safety, with the subject vehicle behind the target vehicle, and the second was referred to as the Rear Extremity Test for lane change safety, with the subject vehicle in front of the target vehicle. In light of the danger inherent in these extremity tests, the driver would press a wireless button on the left side of the steering wheel (shown in Fig. 3) to indicate the lane change process instead of actually changing lanes when they were aware of the appropriate time, as we defined. The appropriate time in the Front Extremity Test was defined as the moment that the lane change behavior of the target vehicle would slightly affect the subject vehicle. The appropriate time in the Rear Extremity Test was described as 'an inevitable conflict with the rear vehicle if the subject vehicle implemented a lane change at that time'. Before the experiment, participants conducted several trial runs to eliminate the possibility of a hysteretic press because of unfamiliarity with the procedure. We selected the G3001 freeway section from Sanqiao to Xinzhu to perform the experiment. The selected freeway section possessed six lanes of two-way traffic. Following the directions of the vehicles in Figs. 1 and 2, vehicles in the inner lane generally have faster velocity than vehicles in the middle lane and the curb lane. We conducted the experiment in clear weather conditions to avoid the impact of weather on driver behavior. In view of the heavy traffic flow during the morning peak and the evening peak, we avoided conducting the test during these times. The traffic flow was moderate during the experiment.

The schematic diagram of the Front Extremity Test is shown in

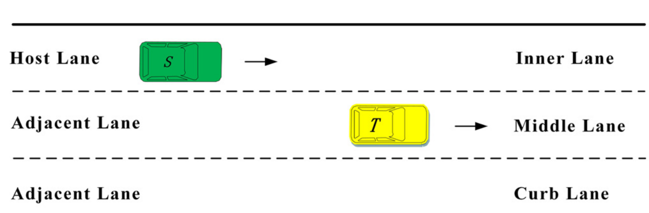

Fig. 1. Front Extremity Test for lane change safety.