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Influence Analysis of Autonomous Cars' Cut-In Behavior on Human Drivers in a Driving Simulator

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Abstract— **To safely, efficiently change lanes among human drivers, autonomous vehicles (AV) should act as close as possible to human to decide when to friendly cut in and seamlessly cooperate with surrounding vehicles. However, it is still not fully clear about how AV cut-in behavior would influence on human drivers. This paper comprehensively analyzes the influence of AV cut-behavior on human drivers in terms of comfort levels over different cut-in scenarios in a driving simulator. The experiment results demonstrate that the relative distance has great influence on the comfort level of human drivers compared to relative speed; and the integrated influence of relative distance and speed between AV and the behind target vehicle have an important role in the influence. These findings could provide an empirical basis for the decision-making design of autonomous vehicles.**

Index Terms— **Autonomous vehicle, cut-in behavior, human drivers, driving comfort.**

I. INTRODUCTION

Cut-in related crashes account for 4%-5% of the total traffic accidents occurred, and it leads to 10% of the total delay time over all traffic accidents [1]–[4]. Although autonomous cars could potentially improve traffic safety, increase traffic efficiency, and release human drivers from complex driving tasks, an inappropriate and unfriendly maneuver by autonomous vehicle could have a negative influence. For example, an aggressive cut-in behavior of autonomous vehicle may put pressures on its surrounding human-driven vehicles and put itself as well as the engaged vehicles in dangerous; inversely, a defensive cut-in behavior of autonomous vehicles may reduce the traffic efficiency. Therefore, it is necessary to develop an appropriate decision-making to help autonomous cars to make a friendly decision, thus allowing autonomous cars to seamlessly blend into the traffic flow. A well understanding of how different cut-in decisions impact human drivers would greatly benefit a human-like and traffic-friendly autonomous vehicle.

In terms of road safety, some works have focused on the effect of cut-in behavior on traffic flow [2], [5], [6]. The effect of a cut-in vehicle on traffic flow on target lanes was investigated, implying that the probability of collision dependents on the speed, speed difference and the initial headway of surroundings [5]. The authors in [2] discussed the different boundaries of four kinds of lane change states including low risk, conflict, near crash and crash imminent to estimate the performance of the cut-in behavior. Some studies [7], [8] focused on the driving behavior of the emerging vehicle. However, these studies take little consideration of the influence of autonomous vehicles on human drivers.

Some work has been focusing on making autonomous vehicles more human-like in motion-planning and decision-making systems, but the effect of these systems on surrounding human drivers' comfort hasn't been covered [9], [10]. For example, some work has focused on the comfort effect of autonomous vehicle on human beings, but primirily on passengers instead of human participants [11]. Okuda and et. al. focused on the impacts of cut-in behaviors on the human drivers of surroundings [12], [13]. From the perspective of three acceptability states (i.e., reject, unknown, accept) of driver on the target lane, some work has been done to realize a better emerging task by discussing related parameters which play an important role in whether the emerging vehicle being accepted or not by the driver at highway junction [12], [13].

However, little work on the influence of cut-in behavior for the autonomous car has been conducted, especially in urban cut-in scenarios. This paper, according to these reasons above, researches the effects of cut-in behaviors of the autonomous vehicle on the human driver of surrounding vehicle on the target lane from the perspective of safety and driver comfort in cut-in scenarios.

The rest structure of the paper is as follows. Section II explains the problem of cut-in behavior for intelligent vehicles. Section III introduces how to design our lane change experiments. The cut-in experiment results and behavior analysis of the results are presented in Section IV. Finally, the conclusion and future works are described in Section V.

II. PROBLEM FORMULATION

The cut-in behaviors in urban and highway environments are totally different. More specifically, the traffic flow has a relatively high speed on highways. But the urban environment has more vehicles and lane change situations, especially in some bigger cities with more population [14]. In this paper, we mainly focus on the typical AVs cut-behaviors in urban environment.

A well-designed autonomous vehicle which can adapt itself to surrounding vehicles could benefit traffic. As shown in Fig. 1, the vehicle A aiming to cut in from right to left should avoid collision conflicts with its surrounding vehicle B, and it would be better to have less effect as possible on

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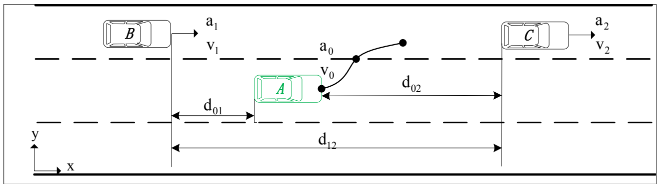

Fig. 1. Diagram of lane change scenario.

B. Here, we make a definition to specify a cut-in trajectory of vehicle A, as shown in Fig. 1.

Definition 1: The drivers of vehicle A and vehicle B are corresponding to driver A and driver B, respectively. The lane where vehicles B and C are driving on is the target lane of the vehicle A.

Cut-in maneuvers are performed by different drivers including defensive and aggressive ones to cover different scenarios in an urban roads, and they vary from different drivers. If driver A wants to take a cut-in maneuver, he or she needs to justify whether the vehicle state is safe enough to cut in successfully. For some drivers, they may cut in in a stable speed under a cut-in scenario, but, for others, they may choose to cut in in a higher speed or acceleration under a same scenario [15]. These two kinds of behavior in the same scenario will lead to different comfort for the surrounding human drivers. In addition, compared to a normal or defensive cut-in behavior, an aggressive one may make surrounding drivers feel unsatisfied. For example, if the driver A aggressively takes a cut-in behavior into the target lane when the space between vehicles A and B is small, then he/she could make the surrounding driver feel uncomfortable. Considering the driver comfort effect on surrounding vehicles, which kind of cut-in decisions is appropriate in urban cut-in scenarios, including when and how to cut in, will be explored in this paper.

III. Driving Simulator Experiment

Existing research [1], [2], [12], [16] has demonstrated that the cut-in behavior of the ego vehicle depends on relative distance, speed difference, rate of change of longitudinal and lateral distances. The speed difference between the current and target lane is great and the cut-in behaviors occur more easily [6], [17]. The relative distance between vehicle A and B plays an important role in whether vehicle B accepts the cut-in behaviors of vehicle A [12]. To explore how these parameters of the cut-in behaviors affect the driver B, we will design the cut-in experiments.

It is time-consuming and dangerous to take real vehicle experiments to investigate which kind of cut-in decision-making behavior is better. Fortunately, the driving simulator could provide us to explore the problem under critical cut-in scenarios.

A. Experiment Design

From the view of driver comfort, this paper investigates the cut-in behavior of vehicle A based on typical cut-in scenarios which can be extended to complicated scenarios [18]. The experiment design and experimental procedure are shown in Fig. 2 [19].

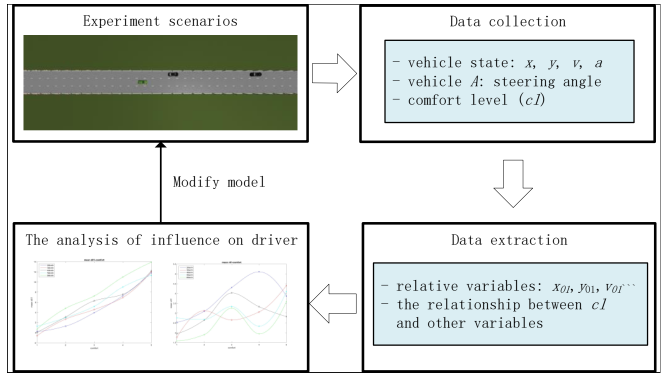

Fig. 2. The process of experimental design

TABLE I
Initial Parameters of Vehicles A, B and C

Initial parameter / Vehicle	Initial position x(m)	Initial velocity(km/h)
A	35	20,30,40,50,60
B	0	20,30,40,50,60
C	-10	20,30,40,50,60

There are three vehicles in our cut-in scenarios as illustrated in Fig. 1. The initial variables are as shown in Table I. The selection of initial positions for three vehicles is based on the principle of reducing the adjustment time before changing lane as much as possible. Also, to simplify the problem, we set the speed of the vehicle B to five constants at five levels, corresponding to five cut-in scenarios in this paper. Here, we denote the relevant variables in Table II.

To ultimately achieve the goal of human-like cut-in behavior and simplify the problem, this paper requires the human driver to control the vehicle B. Vehicles A and B are human-control vehicles, and vehicle C is a leading vehicle which is designed to have little effect on the cut-in behaviors of vehicle A. Vehicles B and C run on the target cut-in lane of the vehicle A. In each scenario, the driver A cuts in based on three different distances listed in Table III.

When the driver A makes a cut-in behavior, the driver B may feel comfortable or uncomfortable. In this paper, according to 5-Point Likert scale, the comfort feeling of driver B is quantified as the comfort level (cl) using five grades [20] shown in Table IV. Based on Table IV, the driver B is required to subjectively evaluate the comfort level for each cut-in behavior of vehicle A. Specifically, we consider three factors including insecurity, uncomfortable, and impoliteness to design five levels of safety and comfort as follows:

- Level 1: Driver B goes through a great security risk for the cut-in behavior when the vehicle A cuts in aggressively. In such case, the driver B has to brake suddenly to avoid accidents and feels strongly uncomfortable, which indicates the driver A behaves rather impolitely.
- Level 2: Driver B is aware that the cut-in behavior of

TABLE II
VARIABLE DEFINITIONS

$v_i(i=0,1,2)$	For $i=0,1,2$, v_i represents respectively the velocity of vehicle A, B and C
$a_i(i=0,1,2)$	For $i=0,1,2$, a_i represents respectively the acceleration of vehicle A, B and C
d_{01}	Distance between the vehicle A and vehicle B
$v_{01}(v_{01}=v_0\text{-}v_1)$	Relative velocity between vehicle A and vehicle B
$a_{01}(a_{01}=a_0\text{-}a_1)$	Relative acceleration between vehicle A and vehicle B

TABLE III
CUT-IN SCENARIOS OVER FIVE CONSTANT SPEEDS

v_1(km/h)	d_{01}(m)	number of test
20	2.5$\sim$7.5, 7.5$\sim$15, $\geq$15	$\geq$33
30	2.5$\sim$7.5, 7.5$\sim$15, $\geq$15	$\geq$33
40	2.5$\sim$7.5, 7.5$\sim$15, $\geq$15	$\geq$33
50	2.5$\sim$7.5, 7.5$\sim$15, $\geq$15	$\geq$33
60	2.5$\sim$7.5, 7.5$\sim$15, $\geq$15	$\geq$33

TABLE IV
COMFORT LEVEL FOR DRIVER B

Level	The feeling of the driver
1	Very poor comfort
2	Poor comfort
3	Moderate comfort
4	Good comfort
5	Very good comfort

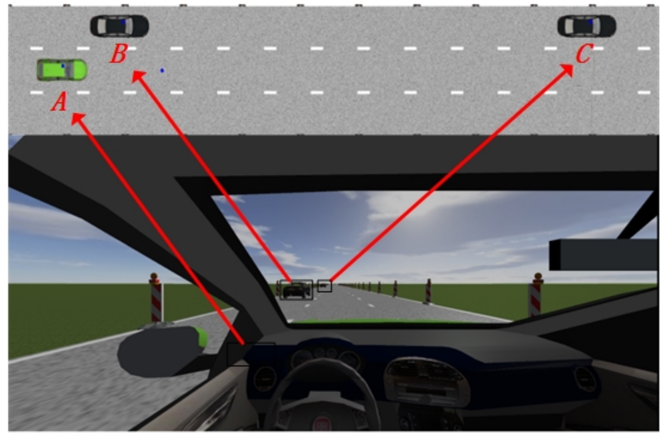

Fig. 3. The driving simulator and experiment scenario

vehicle A may be not safe and needs to slow down to ensure driving safety. In such case, the driver B suffers slightly uncomfortable and thinks that the driver A is impolite.

- Level 3: Driver B can also drive normally with the feeling that the vehicle A drives normally.
- Level 4: Driver B feels that the cut-in behavior of the vehicle A is relatively safe and thus he/she could drive with a small acceleration. In such case, the driver B thinks that the driver A is very polite to give way, and make others comfortable.
- Level 5: Driver B feels quite safe when the vehicle A is cutting in and he even can drive at a large acceleration. In such case, the driver B feels very safe and comfortable.

The cut-in scenarios are built in MATLAB/Simulink and Prescan, where G27 and G29 driving simulators are used in the experiments. The cut-in process is simulated in a traffic situation on a one-way, three-lane city road of 10,000 m. The lane width is 3.75 m. The driving environment and simulator are shown in Fig. 3. All the vehicles are equipped with sensors to collect driving data. The frequency of data collection is 20 Hz. Based on the raw data, the relative distance and relative speed are also extracted to analyze the cut-in behavior. Finally, we obtain the cut-in behavior of the vehicle A and comfort levels of the driver B.

B. Experiment Procedure

In total, five driver participants with 2.5 years of average driving experience, labeled as D #1, D #2, D #3, D #4 and D #5, engage out experiment as driver B, and another driver as driver A controls vehicle A. Each of them operates the vehicle B in all scenarios. For each testing scenario, each driver runs at least thirty-three trials as shown in Table III. So each driver participant takes experiments for no less than 165 trials and finally, 830 trials are conducted in our experiment.

All drivers are trained on the test task for $0 \sim 0.5$ hour before formal data acquisition to be familiar with the driving simulator including normal driving, acceleration, and deceleration. After they get used to the experimental task and comfort evaluation criteria, they are initially instructed to drive the virtual vehicle B and report the comfort. The formal test and data collection begin when the drivers are familiar with how to control the speed and direction of the vehicle and the cut-in process to ensure the validity of the collected data [12], [21].

To be specific, there are some requirements for vehicles A, B and C as follows:

- The driver A is required to control the vehicle A to cut in in the five scenarios.
- The driver B is required to control the speed and driving direction of the vehicle B at each constant speed as stably as possible. In addition, when the driver A cuts in, the driver B can take action to accelerate, brake, etc. in different scenarios, and evaluate the comfort level after completing the cut-in task based on the comfort evaluation criterion.
- Vehicle C could automatically adjust speed to keep close to that of the vehicle B.

When the vehicle A finishes the cut-in task, the driver B of the target lane is asked to make a comfort evaluation according to the evaluation criterion. Note that, to reduce the effect of driving fatigue on the driving process and comfort evaluation, a 5 $\sim$ 10 minute break per hour for all drivers was taken.

IV. Experiment Results and Analysis

Through multiple trials, we collected multiple cut-in samples, and then extracted the cut-in data for all cut-in samples to analyze the cut-in behaviors. For the sake of behavior analysis, here, we make definitions for the cut-in behavior of vehicle A:

Definition 2: The cut-in moment t is defined as the moment when the left front tire of the vehicle A rolls the lane line between the current lane and target lane.

Definition 3: The cut-in state is defined as the average state of driving states for vehicle A from $(t - 0.25$ s) to $(t + 0.25$ s). Note that since the cut-in model gathers data per 0.05 s, we select 10 sampling points of the data.

According to the previous research and our observation, the relative distance and relative speed between vehicles A and B have certain effect on surroundings [12]. This section will analyze the relationship between d_{01}, v_{01} and corresponding comfort level of the driver B.

It is not difficult to understand that different d_{01} and v_{01} affect the comfort level. To be specific, the larger these two parameters are more comfortable driver B feels. But it may be hard to describe how and what extent the influence is. This section will analyze the results of cut-in experiments to try to obtain quantitative results.

A. The Influence of d_{01} or v_{01} on Comfort for All Drivers

Figs. 4 and 5 show cut-in samples for d_{01}, v_{01} and comfort level for D #1 $\sim$ #5 in cut-in scenarios, where, Figs. (a) $\sim$ (e) correspond to five cut-in scenarios (20 km/h, 30 km/h, 40 km/h, 50 km/h and 60 km/h) respectively. Each dot sample in these two figures represents the relationship between the cut-in behaviors of driver A in five scenarios and the comfort level evaluations of five driver B according to the comfort criterion in Section III.

From Fig. 4 (a)-(e), we could clearly find that the comfort levels tend to be much higher when d_{01} is bigger in any cut-in scenario. In other words, greater the relative distance d_{01} is, more comfortable driver B feels. So when we design the decision-making system of the autonomous vehicle in cut-in scenarios, we need to take d_{01} into consideration to make the surrounding human drivers feel comfortable. In addition, in our scenarios vehicle A and B may crash and the driver B feels strong disgust since the distance between vehicle A and B for some samples is extremely close, that's why we could find 63 samples in Fig. 4 that $d_{01} < 0$ when $cl = 1$. Vehicle A should be designed to cut in without collisions with vehicle B to ensure the traffic safety. So, to ensure the comfort of the human driver and the safety of traffic, the d_{01} when $cl = 1$ should be avoided.

Fig. 5 (a)-(e) shows the relationship between v_{01} and comfort level for D #1 $\sim$ #5, which is not obvious as that for d_{01}. In these five cut-in scenarios, the majority of v_{01} vary randomly from 0 to 7 m/s for five kinds of comfort levels, for

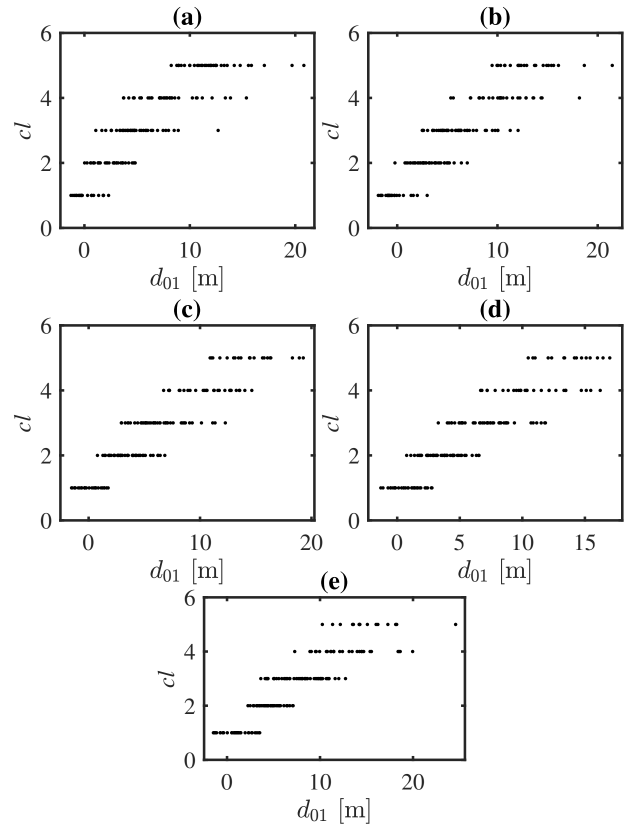

Fig. 4. The influence of d_{01} on the comfort evaluation for D #1 $\sim$ D #5 in five cut-in scenarios

example, in Fig. 5 (c), we can find that v_{01} is large or small in every comfort level. But the v_{01} of the majority samples in lower comfort levels tend to be relatively small compared to those in higher comfort levels, such as $cl = 1$ and $cl = 4$. We can also find the v_{01} has a slightly increasing trend when the speed of cut-in vehicle increases as shown from Fig. 5 (a) to (e), which indicates driver A may tend to cut in with a much higher v_{01} in relatively high-speed scenarios than in relatively low-speed scenarios.

B. The Influence of d_{01} or v_{01} on Comfort for Driver #1

We take all the experiment data of Driver #1 for an example to analyze the decision-making behavior in cut-in scenarios.

1) The mean and standard deviation of d_{01} or v_{01}: The means and standard deviations (std) of d_{01} and v_{01} for different comfort levels for D #1 in five kinds of scenarios are respectively shown in Figs. 6 and 7, and we could also observe the same trend for d_{01} and v_{01} as Figs. 4 and 5.

From Fig. 6, we can find that for five scenarios sums of mean and std, and the means of d_{01} fluctuate around 0 m when $cl = 1$ which means vehicles crash or approach to the crash; for $cl = 2$ and 3, the means of d_{01} in 20 km/h scenarios are approximately 2.5 m larger than those in 60

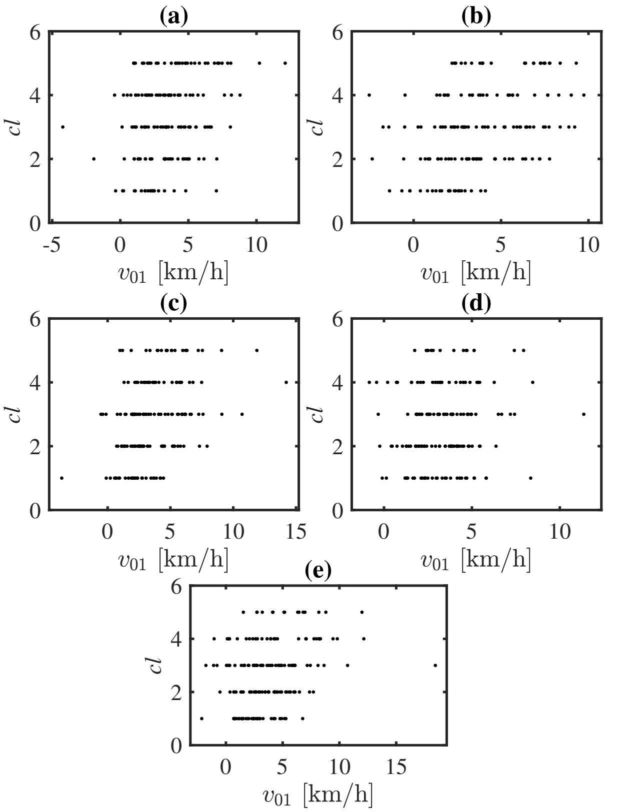

Fig. 5. The influence of v_{01} on the comfort evaluation for D #1 $\sim$ D #5 in five cut-in scenarios

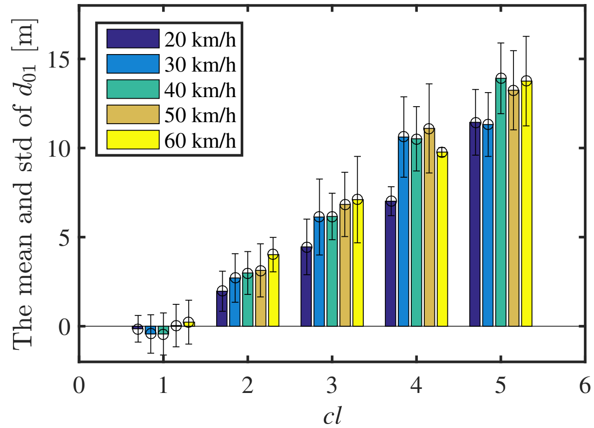

Fig. 6. The mean and std of d_{01} for different comforts for D #1 in five cut-in scenarios

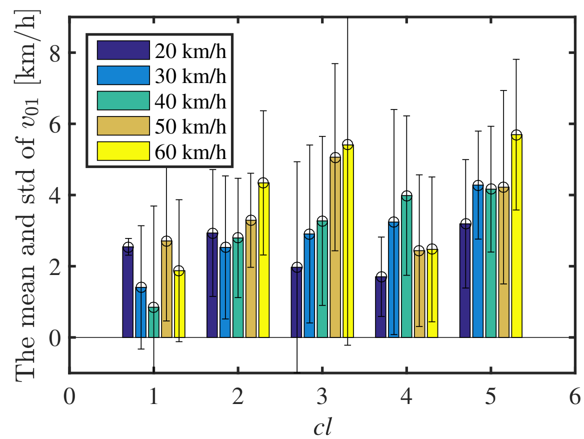

Fig. 7. The mean and std of v_{01} for different comforts for D #1 in five cut-in scenarios

km/h scenarios, while in other three scenarios, the means are relatively close and among those of previous two scenarios; for $cl = 4$, the means of d_{01} in 30 $\sim$ 60 km/h scenarios are around 10m, and for $cl = 5$, the means are relatively close to those for $cl = 4$, which represents the effect of d_{01} on comfort levels reduces when $cl = 4$ and 5. Besides, from the std of d_{01}, we can find that the cut-in behaviors for D #1 collected in this paper has some randomness which can be regareded as typical samples for cut-in behaviors. Fig. 7 shows that the effect of v_{01} may be not obvious as that of d_{01}. In the figure, we could find that the mean of v_{01} tends to be relatively low when $cl = 1$ compared to $2 \sim 5$.

2) The Comprehensive Influence of d_{01} and v_{01}: The comprehensive influence of d_{01} and v_{01} on comfort level for D #1 in five cut-in scenarios are shown in Fig. 8. In the figure, there are 5 kinds of comfort levels as previously mentioned, which shows bigger the comfort level is, more comfortable D #1 feels for the cut-in behavior of driver A. From the figure, we can also find that for D #1 the d_{01} has a great effect on the comfort level, and v_{01} slightly affects it. It shows the comfort level tends to be 1 when $v_{01} < 3.5$ m/s and $d_{01} = 1$ m, while it tends to be 2 when $v_{01} > 3.5$ m/s and $d_{01} = 1$ m. The similar tendency happens when $d_{01} = 14$ m, i.e. the comfort level changes from 4 to 5 when $v_{01} = 4$ m. It shows that the effect of v_{01} on comfort level increases with the increase of d_{01}. So when we design the decision-making system for an autonomous vehicle, we can regard d_{01} as a major factor, and assign different weights to v_{01}.

When $cl = 1$ and 2, the driver B feels uncomfortable and unsafe, so we think the cut-in behaviors of driver A in these scenarios are very dangerous. To ensure the traffic safety and comfort of the human driver of surrounding vehicle, we take the cut-in behaviors when $cl = 3$ as the lowest driving behavior, which could be designed into a pattern for autonomous vehicles in cut-in scenarios. And when the passengers are in a hurry to go to work or do something, the autonomous vehicles can choose this driving pattern which is a most appropriate cut-in condition to minimize the time on the way as soon as possible on the basis of avoiding change-lane crashes. In addition, the behaviors when $cl = 4$ and 5 could be regarded as different patterns for autonomous vehicles which can be chosen considering influence extent on surroundings.

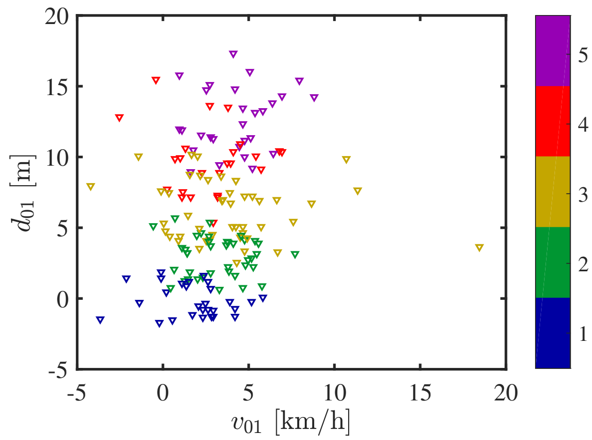

Fig. 8. The relationship between v_{01} and comforts for D #1 in five cut-in scenarios

V. Conclusion

This paper investigated the influence of autonomous vehicle's cut-in behavior on human drivers' comfort levels and safety in a driving simulator. Five kinds of comfort levels was set. In all the five scenarios, we obtained the appropriate cut-in behaviors including the relative distance and relative speed between surrounding vehicles and autonomous vehicles, which balances the traffic safety and the comfort levels of human drivers. The experiment results demonstrate that the relative distance selection has a great impact on the comfort of surrounding drivers. Even though is the effect of v_{01} weak, we can still consider the effects of both d_{01} and v_{01} on human drivers to endow the autonomous vehicles choose the appropriate cut-in decision. This research results not only provide a theoretical guideline for designing an appropriate cut-in decision-maker for autonomous vehicles but also offer a reference to evaluate the decision-making systems of autonomous vehicles. In our future work, more complex cut-in scenarios will be conducted, including active and passive lane change scenarios, the balance between the driver comfort and the efficiency of the traffic flow, and the interaction behaviors between autonomous vehicles and surrounding vehicles.

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References

[1] Jin Li-sheng, Fang Wen-ping, ZHang Ying-nan, Yang Shuang-bin, and Hou Hai-jing. Research on safety lane change model of driver assistant system on highway. In *Intelligent Vehicles Symposium, 2009 IEEE*, pages 1051–1056. IEEE, 2009.

[2] David L Smith, Richard Glassco, James Chang, and Daniel Cohen. Feasibility of modeling lane-change performance. Technical report, SAE Technical Paper, 2003.

[3] Volvo Trucks. European accident research and safety report 2mi3. 2013.

[4] Anurag Pande and Mohamed Abdel-Aty. Assessment of freeway traffic parameters leading to lane-change related collisions. *Accident Analysis & Prevention*, 38(5):936–948, 2006.

[5] Yuichi Naito and Takashi Nagatani. Effect of headway and velocity on safety–collision transition induced by lane changing in traffic flow. *Physica A: Statistical Mechanics and its Applications*, 391(4):1626–1635, 2012.

[6] Zuduo Zheng. Recent developments and research needs in modeling lane changing. *Transportation research part B: methodological*, 60:16–32, 2014.

[7] Zuduo Zheng, Soyoung Ahn, Danjue Chen, and Jorge Laval. The effects of lane-changing on the immediate follower: Anticipation, relaxation, and change in driver characteristics. *Transportation research part C: emerging technologies*, 26:367–379, 2013.

[8] Jinxian Weng, Shan Xue, and Xuedong Yan. Modeling vehicle merging behavior in work zone merging areas during the merging implementation period. *IEEE Transactions on Intelligent Transportation Systems*, 17(4):917–925, 2016.

[9] Dorsa Sadigh, Shankar Sastry, Sanjit A. Seshia, and Anca D. Dragan. Planning for autonomous cars that leverage effects on human actions. In *Robotics: Science and Systems*, 2016.

[10] V Butakov and P Ioannou. Driving autopilot with personalization feature for improved safety and comfort. In *IEEE International Conference on Intelligent Transportation Systems*, pages 387–393, 2015.

[11] Hillary Abraham, Chaiwoo Lee, Samantha Brady, Craig Fitzgerald, Bruce Mehler, Bryan Reimer, and Joseph F Coughlin. Autonomous vehicles, trust, and driving alternatives: A survey of consumer preferences. In *Transportation Research Board 96th Annual Meeting, Washington, DC*, pages 8–12, 2017.

[12] Hiroyuki Okuda, Kota Harada, Tatsuya Suzuki, Shintaro Saigo, and Satoshi Inoue. Modeling and analysis of acceptability for merging vehicle at highway junction. In *Intelligent Transportation Systems (ITSC), 2016 IEEE 19th International Conference on*, pages 1004–1009. IEEE, 2016.

[13] Hiroyuki Okuda, Kota Harada, Tatsuya Suzuki, Shintaro Saigo, and Satoshi Inoue. Design of automated merging control by minimizing decision entropy of drivers on main lane. In *Intelligent Vehicles Symposium (IV), 2017 IEEE*, pages 640–646. IEEE, 2017.

[14] rn Dogan, Johann Edelbrunner, and Ioannis Iossifidis. Autonomous driving: A comparison of machine learning techniques by means of the prediction of lane change behavior. In *IEEE International Conference on Robotics and Biomimetics*, pages 1837–1843, 2011.

[15] Daniel Sun and Lily Elefteriadou. A driver behavior-based lane-changing model for urban arterial streets. *Transportation Science*, 48(2):184–205, 2014.

[16] Kentarou Hitomi, Hitoshi Terai, Hiroyuki Okuda, Takashi Bando, Chiyomi Miyajima, Takatsugu Hirayama, Yuki Shinohara, Masumi Egawa, and Kazuya Takeda. Effect of automatic lane changing on drivers behaviour decision process? In *FAST-zero'15: 3rd International Symposium on Future Active Safety Technology Toward zero traffic accidents, 2015*, 2015.

[17] Jorge A Laval and Carlos F Daganzo. Lane-changing in traffic streams. *Transportation Research Part B: Methodological*, 40(3):251–264, 2006.

[18] Julia Nilsson, Jonatan Silvlin, Mattias Brannstrom, Erik Coelingh, and Jonas Fredriksson. If, when, and how to perform lane change maneuvers on highways. *IEEE Intelligent Transportation Systems Magazine*, 8(4):68–78, 2016.

[19] Quoc Huy Do, Hossein Tehrani, Seiichi Mita, Masumi Egawa, Kenji Muto, and Keisuke Yoneda. Human drivers based active-passive model for automated lane change. *IEEE Intelligent Transportation Systems Magazine*, 9(1):42–56, 2017.

[20] Y G Kim, H B K Won, S W Kim, C K Kim, and T W Kim. correlation of evaluation methods of ride comfort for railway vehicles,. *Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail and Rapid Transit*, 217(2):73–88, 2003.

[21] Holly EB Russell, Lene K Harbott, Ilana Nisky, Selina Pan, Allison M Okamura, and J Christian Gerdes. Motor learning affects car-to-driver handover in automated vehicles. *trials*, 6(6):6, 2016.