Understanding Behavioural Conflict between the Drivers and Adaptive Cruise Control (ACC) System in Cut-in Scenario

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Abstract: In the cut-in scenario of the ACC system, there is often a lack of harmony between people and cars due to the limitations of sensors and control strategies. Finding and solving the conflict between the driver and the machine is essential to achieve harmonious Human-Machine Cooperation. This research is to understand the conflict between the driver and ACC system in the cut-in scenario based on the previous work of driver trust experiment. The research selected eight drivers for in-depth interview, and the results showed that the biggest conflict between the driver and ACC was that the driver's cognitive and behavioural patterns were significantly different from the ACC system. It is mainly reflected on three aspects: the different definition of the cut-in scenario, the risk perception and the stress of the impending danger, and the perceptual process of cut-in scenario. In order to reduce human-machine conflict, the research proposed three design strategies: (1) Redefine the cut-in scenario based on the driver's cognition. (2) Keep the ACC human-machine interface consistent with the driver's psychological perception. (3) Help drivers cope with dangerous scenario with three levels of warning signals: guidance information, warning information and takeover information.

1 INTRODUCTION

The Advanced Driving Assistant System (ADAS) can help drivers reduce burdens and improve safety, comfort and convenience in driving, and has been widely used in recent years. With the development of sensor technology and data acquisition and processing technology, sensory deficits of the driver are compensated by technical sensors; for example, the limited vision at night of drivers is enhanced by night vision systems. These domains are commonly referred to Human-Machine Cooperation (HMC) and Cooperative Systems (COS) (Bengler K et al., 2012). Hoc (Hoc, 2001) has detailed a precise definition of cooperation that is consistent with most of the literature:

Two agents are in a cooperative situation if they meet two minimal conditions. (1) Each one strives towards goals and can interfere with the other on goals, resources, procedures, etc. (2) Each one tries to manage the interference to facilitate the individual activities and/or the common task when it exists. The symmetric nature of this definition can be only partly satisfied (Hoc, 2001).

The Adaptive Cruise Control (ACC) is a comfortable, intelligent driving assist that can maintain a steady state of driving depending on the driver's pre-set speed and pre-set distance. But in some scenarios, there are still limitations. As shown in Fig.1, the cut-in vehicle changes lane and becomes the new front vehicle for the ACC system, but the ACC is not always quick to identify and lock the front

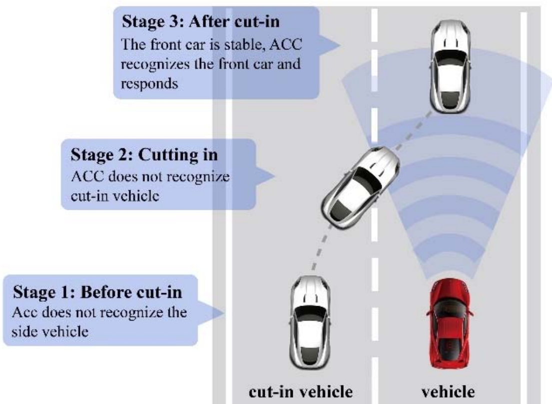

Figure 1: The response of ACC in cut-in scenario.

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vehicle. If the speed at which the ACC system is set faster than the current speed of the vehicle, the vehicle will continue to accelerate until one of the following events occurs: the system reaches its set speed; the system recognizes and catches the new guided vehicle; the driver takes over the ACC system (Larsson et al., 2014).

The driver takes over ACC without being prompted, which means that the disruption of human-machine cooperation of controling the vehicle. The study by Frank et al., (2012) suggests that the dynamic balance of the human-machine system must have a cycle of perception, decision-making, and action (Fig.2). In the perceptual stage, the difference between the driver and the human-machine system is the greatest. Firstly, the two are different to the perception of the environment and the judgement of the danger. Secondly, the cut-in scenario is a short dynamic process, which may increase the cognitive load of drivers, and requires the driver to have sufficient situational awareness and reaction ability. Thirdly, the takeover itself is a behaviour that requires high perception load, which leads to a longer reaction time (Tsang-Wei Lin, 2009). All of these has implications for drivers taking over ACC.

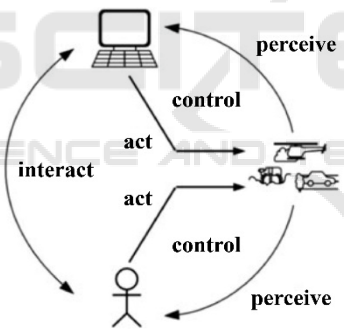

Figure 2: The response of ACC in cut-in scenario.

In previous studies. Pengjun et al., (2005) showed that the degree to which drivers take over ACC manually depends on a number of factors, and an important one is the difference between the ACC's performance and the driver's expectations. This is consistent with Wouter (Wouter et al., 2017) and Bobbie (Bobbie et al., 2015). In Brian's research (Brian et al., 2012), it is pointed out that how drivers make decisions is not based on external circumstances, but based on perceived mental representations. In the cut-in scenario, the driver's mental representation is consistent with the ACC's control strategy, which directly leads to the driver taking over the vehicle to avoid risk. Because the psychological model of different drivers is different, their mental representations will be changed according to the degree of familiarity and degree of trust of the ACC system. It is almost impossible to get the ACC system's control strategy exactly the same as the driver's mental model, but it can reduce the difference between the perceptual stage in the human-machine interface: not only should the driver be notified of the behaviour and state of the ACC system, but also the driver should be guided by the driver's perception of the cut-in scenario.

In recent years, scholars have come up with new ideas about how to design Intelligent Manufacturing Systems (IMS), replacing techno-centered design with human-centered design. Some scholars have worked on Human-Machine Cooperation, Levels of Automation and Situation Awareness, and Human-Automation Symbiosis (May et al., 2014; Millot, 2014; Romero et al., 2015.) (Pacaux-Lemoine et al., 2017). In order to improve the efficiency of human-computer interaction, the study of Bjørn Solvang et al., (2012) discusses the cooperative mode and interaction between human operators and machines, and presents an open control system for new and old equipments. The study by Oborski (Oborski et al., 2004) suggests that the whole system performance depends on human decisions, and the significant stress should be put on the problem of human-machine and human-computer systems co-operation. In Pacaux' study (Pacaux et al., 2017) proposed a principle to retain humans in the process control loop with different levels of involvement identified by the levels of automation.

This research is also based on the idea of human-centered design, studying how people and machines can collaborate better and improve people's productivity.

2 RESEARCH METHOD

2.1 ACC Cut-in Scenario Analysis

This study discusses the human-machine relationship and driving condition of the driver and ACC system in the cut-in scenario. It is pointed out that the human-machine collaborative control is the ideal state of human-machine interaction, which provides the basic theoretical guidance for in-depth interview and human-machine interface design.

The state of human-machine driving can be divided into four types according to the role of driver and machine in driving a vehicle: both of them leave it alone; the vehicle is driven by the intelligent driving

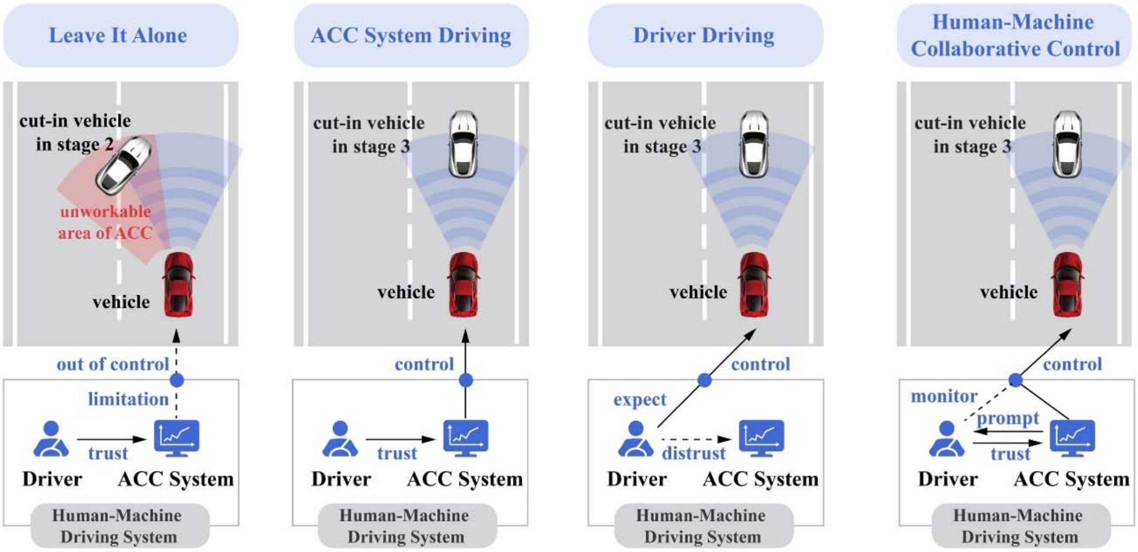

Figure 3: Human-Machine cooperative driving status of ACC in cut-in scenario.

system (ACC); driver controls the vehicle; driver and intelligent driving system (ACC) work together to control vehicles through human-machine interface.

As shown in Fig.3, in the ACC cut-in scenario, these four conditions are:

(1) The machine is left unattended: because of the shortcomings of the ACC sensor, it was unable to identify the side vehicles. And because of the driver's trust in ACC, the driver may not have noticed the side vehicle during the side car's cutting-in.

(2) Intelligent driving system (ACC) controls the vehicle: the vehicle senses the cut-in vehicle and processes it before the driver intervenes. The premise of this is that the ACC is fully trusted, but this leads to two results: the ACC's steady and safe completion of the vehicle task; and the ACC's delay in the driver's expectation, which reduces the driver's trust in the ACC system.

(3) The driver controls the vehicle: the vehicle senses the cut-in vehicle, but the brake time is later than the driver's expectation, or the two vehicles' distance is less than the driver's safety expectation, and the driver takes over vehicle initiatively. Another is when the car and the side car driving normally. However, people have the ability to predict and feel that the side car want to cut in, then he takes over in advance when the side car gets closer and closer to the side lane line.

(4) Human-machine cooperative control: the vehicle will perceive information such as the current state and behaviour of ACC, current environment information, etc., through the interactive interface to the driver. ACC system can actively decelerate, and human interface can warn the driver in advance, so that the driver can take over in time.

2.2 Experimental Design and In-depth Interview

The interview was based on a previous work that researches the driver's trust in the ACC in cut-in scenario. The experiment uses v-box to capture the actual driving video (the dashboard interface and the external environment, both in sync) when the Volvo XC90 turns on the ACC and cuts in. As shown in fig.4, the experiment simulated real-life road scenes on a driving simulator, and placed the dashboard video on the iPad in front of the steering wheel to simulate the real dashboard. The experiment has set up six conditions, respectively, the speed of the car was V=30km/h, 50km/h, 60km/h, and the distance between the two vehicles was THW=0.7s, 1.2s. By evaluating drivers ' trust in ACC to understand the relationship between drivers and ACC, the results showed that the speed and THW values had a definite effect on the level of trust that the driver had when he started the ACC: at the same speed, the lower the value of THW, the lower the level of trust the driver is.

Although it is possible to quantify human-machine relationships through trust evaluation, it is difficult to understand the deep information, such as the driver's distrust of ACC. What is the driver's real concern? What is the cause of the conflict between the driver and ACC? Based on the above questions, this study uses a in-depth interview method to get a better understanding of the behaviour and thoughts of the driver in the cut-in scenario, providing in-depth analysis of the driver's behaviour in this experiment. The in-depth interview is a qualitative research method. Researchers with specialized access skill to

Figure 4: Experimental environment.

to treat a certain condition to the access object, uses the unstructured method to carry on the personal conversation type visit, in order to reveal the hidden secret about the specific behaviour, the motive, the purpose, the attitude, the feeling report and discovers its inner connection (Yuan Yue et al., 2006). The conclusion of this study is based on this method.

The interview outline is designed to focus on the driver's experience in cut-in scenario when driving simulator, and interview the driver's subjective feelings and objective behaviour during the experience. The subjective experience includes the feeling of response during the process of cut-in, the time and influence of the danger consciousness, and the situational awareness of the ACC human-machine interface. Objective behaviour refers to the braking response of the driver in the ACC cut-in scenario.

The selection of the participants mainly considered the degree of understanding of the ACC system, the experience of using ACC system, the driving experience and several factors of age. The study selected 8 participants, 4 males and 4 females, aged 20 to 30 years old, who had some knowledge of the ACC system and had a 1-2year driving experience. The selection of younger users is mainly due to the fact that the cut-in scenario has high level requirements for the user's situational awareness and responsiveness. The younger users can respond faster, so that we can get more detailed interview data.

The interview is about 30-40 minutes, a week in length and is visited in the Automotive Media Lab of Tongji University. During the interview, first, the participants were introduced to the driving simulator and the ACC. Then, the main interview purpose was explained, and the participants were allowed to practice driving for 10 minutes. Afterward, each participant was shown a video of the ACC's cut-in scenario in six different conditions, and during the experience, the participants were able to turn the steering wheel or brake based on their perceptions of the driving scene, and the observers recorded their behaviour. Finally, after the experience was over. In the form of access, a semi-structured outline was adopted, and the participants were able to say how they felt in the cut-in scenario, and the facilitator pursued the key questions based on the actions and thoughts of the interviewees. In order to ensure the authenticity and correctness of the interview, this study used a recording pen to record the interview contents, and then collated the documents and send it to the participants to confirm.

3 RESULTS

3.1 In-depth Interview Results Analysis

The driver's prediction of the behaviour of the cut-in vehicle's driver in the cut-in scenario affects the take-over behaviour. In all conditions, the driver is always more likely to choose to brake than to feel the danger. Of the 8 participants, 5 said that they were still taking the brake when they were not feeling the danger because of the predicting driver's behaviour of the side car during driving. If the side car was too close to the side lane, the driver might have an idea of the cutting-in. So when the side car was near the side lane line, the participants were already alert and ready to brake. In one typical case, in one of the test scenarios, the car's speed V = 50km / h, THW = 1.2s, only one of the participants felt dangerous, but the number of people taking the brake was 4. The reason for this is that in the cut-in scenario, the side car continued to drive for 1-2 seconds near the side line before cutting in, which causes the drivers to take the brake. From this we can recognize that the driver and ACC are different in their definition of the cut-in scenario.

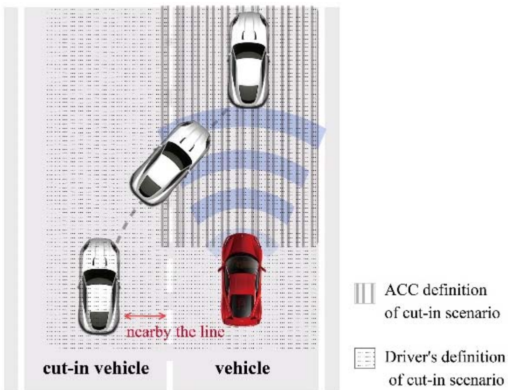

Figure 5: Different definitions of driver and ACC for cut-in scenario.

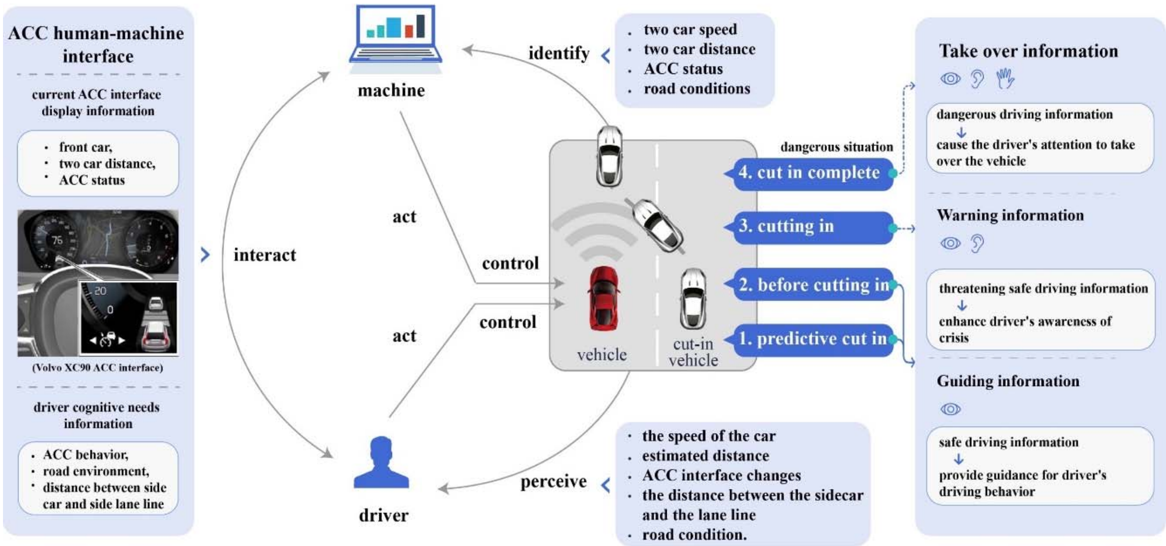

Figure 6: Human-machine interface design strategy in ACC cut-in scenario.

As shown in Fig. 5, for the driver, the cut-in scenario is more than just the vehicle's cutting-in process, but also the stage where the pre-sensing side car is about to cut.

In the cut-in scenario, the driver focuses more on the actual distance between the two cars (the actual distance = V THW) than the speed or THW. According to the researcher's observation, when the THW is constant, the lower the speed (V=30km/h), the greater the driver feels dangerous and brakes, which seems to contradict the common sense that we generally believe that the speed is higher and more dangerous. For example, in the cut-in scenario, when THW=1.2s, V=60km/h, the distance between the two vehicles is 20.00m, 1 participants brake; when V=50km/h, the distance between the two vehicles is 16.67m, 2 participants brake; and V=30km/h, the distance between the two vehicles is 10.00m, and 5 people brake. As the two cars get closer and closer, the more dangerous the driver is feeling. According to the in-depth interview, two participants said that as they got closer and closer to the front car, there was a looming pressure, heightened awareness of the danger, and therefore braking.

The ACC human-machine interface is less helpful to the driver in the cut-in scenario. Of the 6 conditions, 4 of them have 2 respondents who thought that the ACC human-machine interface was helpful, and the remaining 2 conditions were 3 and 4 respectively. One participants said the reason why the ACC human-machine interface wasn't helpful was: " when I (focus) drive, and I can look out for information. "According to the researcher's further confirmation, the interviewee's priority in the process was the external environment in the process of cutting in. According to the interview, all the participants said they were in a situation where they felt the danger, the moment when the side car cut-in, focused on the environment outside the car and the distance between the car and the cut-in car. After the side car cut-in and had been steadily moving, they would pay attention to the ACC system and understand its status display.

3.2 Human Machine Interface Design Strategy

In the cut-in scenario, the performance of the ACC human-machine interface is not satisfactory to the driver. The main reason for the conflict is that the driver is considering are very different from the ACC, which is mainly reflected in three aspects: the different definitions of the cut-in scenario, the different between the perceived risk factors and the stress, and the perception of the cut-in scenario.

In order to achieve a harmonious human-machine interaction and reduce the conflict between the driver and ACC, the ACC human-machine interface should be designed according to the driver's cognition and thinking model, as shown in Fig.6.

(1) Firstly, it is important to redefine the cut-in scenario, to expand the concept of the cut-in process to four stages: anticipative cut-in, before cut-in, cutting in, and after cut-in. The predictive behaviour of the side vehicle’s driver can be judged by the distance between the side car to the side lane line. When the side car is closer and closer to the side lane line, the side driver is considered to have the intention

of cutting, and the driver should be informed of the human-machine interface.

(2) Secondly, in view of the driver's perception of danger and pressure, the ACC human-machine interface can be combined with the multi-sensory channels such as interface display, sound, vibration, etc. to convey the situational pressure when the distance between the two cars is reducing. So that ACC human-machine interface is consistent with the driver's psychological cognition. In the design study of Bobbie et al., (2007), changes in size and shape (trapezoid and triangle) was used to show the behaviour of the ACC and the danger of the current driving scenario, so as to consistent with the driver's perception of the dangerous scene.

(3) Finally, in response to the driver's perception of the ACC cut-in scenario, the ACC human-machine interface should not only inform the driver of the status and behaviour of the ACC, the road condition, the driving environment, etc (Bobbie et al., 2015). but also the driver should be warned in advance to help the drivers deal with unexpected situations.

In the study of Bako (Bako et al., 2006), the researchers also noted that ACC's early warning of drivers could help drivers cope with dangerous scenarios. The early warning should be gradual and hierarchical. According to the importance of the information and the degree of impact to safe driving, it is divided into three levels: the first is the guide information which about safe driving. This level uses only the visual perception channel, displays on the interface, plays the guiding role for the driver's driving behaviour. In the cut-in scenario, the guidance information should be displayed in the first two stages: perception cut-in and before cut-in, giving the driver an understanding of the current road conditions and trends.

The second level is the warning information for the possible threat of safe driving. In order to enhance the driver's awareness of crisis, using both visual and auditory channels. In the cut-in scenario, it corresponds to the cut-in phase. When the cut-in vehicle threatens to safe driving, a note is sounded, and the warning interface is displayed on the dash board, causing the driver to be alert. The third level is to take over information which may cause a traffic accident and need an emergency take over. In this level, three sensing channels are used to attract the attention of the driver to take over the vehicle: vision, hearing and touch. In the cut-in scenario, when the vehicle is cut-in completely and threatens to safe driving, the user will be prompted to take over the vehicle by displaying the danger information, prompting the sound and shaking the steering wheel.

4 CONCLUSION

In order for the driver and ACC to achieve a harmonious human-machine cooperation and improve efficiency and safety of driving, we should clearly recognize the differences and conflicts between drivers and ACC in the cut-in scenario. The biggest conflict is that drivers and ACC have different definitions of the cut-in scenario, the perceptions of danger and abilities to afford pressure of impending danger, and the context-aware content and processes of environmental perceptions. There are two ways to reduce this divergence. One is to make the ACC system's sensor performance enhanced, the control strategy more humane, and have the ability to learn and record the driver's driving habits and driving behaviour, making the ACC system more and more consistent with the driver's expectations. The second way in which the vehicle and the ACC can detect information and convey to the driver through the human-machine interface by using different sensory channels based on the degree of danger, and allow the driver to use the strength of ACC to expand his abilities as much as possible.

At present, the second approach, it seems, is easier to implement and less costly. The human-machine interface design, which is designed to reduce the conflict between the driver and the machine, is crucial to understanding the conflict between the two. Based on this purpose, this research obtains first-hand information through in-depth interviews, analyzes the behaviour and thoughts of drivers in the cut-in scenario, and proposes three design strategies for the cut-in scenario, which has certain practical significance. However, this study still has limitations. One of the most important is the inability to fully respond to all ages, and the behaviours and thoughts of other drivers in the process of cut-in scenario will enrich our understanding of this problem.

The method human-machine interface design proposed in this study is mainly aimed at the ACC cut-in scenario, which can be used in other driving scenarios, and even provides some ideas for the design of intelligent human-machine system to help drivers better cope with various driving situations and achieve harmonious human-machine cooperation. These questions will be further explored in future studies.

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