Safety Science 72 (2015) 116–126

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Reaction to a critical situation during driving with Adaptive Cruise Control for users and non-users of the system

Giulio Francesco Bianchi Piccinini [a,b,*], Carlos Manuel Rodrigues [c], Miguel Leitão [d], Anabela Simões [e]

[a] Chalmers University of Technology, Department of Applied Mechanics, Division of Vehicle Safety, Accident Prevention Group, Lindholmspiren 3, Lindholmen Science Park, 41756 Göteborg, Sweden
[b] ISEC UNIVERSITAS, Alameda das Linhas de Torres 179, 1750-142 Lisboa, Portugal
[c] CITTA, Departamento de Engenharia Civil, Faculdade de Engenharia, Universidade do Porto, rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[d] Instituto Politécnico do Porto, Rua Dr. António Bernardino de Almeida 431, 4200-072 Porto, Portugal
[e] CIGEST, Rua Vitorino Nemésio 5, 1750-306 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 9 March 2014
Received in revised form 3 September 2014
Accepted 7 September 2014

Keywords:
Human factors
Driving simulator
Mental model
Trust
Behavioural adaptation

ABSTRACT

Adaptive Cruise Control (ACC) is a system that maintains driver-selected speed and headway to a preceding vehicle. The system presents some limitations that are, in part or totally, unknown to the users. Hence, many drivers exhibit a rudimentary mental model of the system and place excessive trust in the device. As a consequence, negative effects on road safety can easily occur. However, to date, many studies conducted on ACC have comprised participants who had never used ACC previously. Therefore, there is limited knowledge of how ACC affects the driving performance of experienced users of the system. To shed light on this point, twenty-six participants, divided into two groups (ACC users and non-users) drove twice in the simulated environment (once with the ACC and once manually). During both drives, the participants experienced a critical situation (stationary vehicle stopped in the cruising lane of the highway). The results show that negative behavioural adaptations to the ACC resulted from the usage of the system with regard to the critical situation: the risk of collision during the driving with ACC was increased compared with the manual driving for both groups of drivers. Besides, the research stresses the negative large correlation between the driver's mental model of ACC operation in the critical situation and the safety margins maintained by the ACC users during the same situation. Finally, it was found that the drivers' trust in the system does not have an influence on the drivers' behaviour during the trial with the ACC.

1. Introduction

1.1. Adaptive Cruise Control

As one of the earliest Advanced Driver Assistance Systems (ADAS) to be introduced on the market, the Adaptive Cruise Control (ACC) system provides the partial automation of the vehicle's longitudinal control and alleviates the driver's workload in a convenient manner (International Organization for Standardization, 2010). The system was first accessible in Japan in 1995 and later in Europe and in the USA mainly for high-end vehicles and recently spread also to the mid-range (Bishop, 2005). In the future, the ACC will be available on lower grade vehicles (Young, 2012), which justifies the significant number of studies conducted on the system in recent years. During ACC use, the driver can set the desired speed and headway using buttons on the steering wheel or lever switches, and the system reacts based on the following logic: if the system does not detect a preceding vehicle, the subject vehicle's speed is maintained equal to the setting specified by the driver. However, when the system detects a vehicle in the trajectory ahead, the vehicle's speed will be adjusted to maintain the value of headway imposed by the driver. In this second working modality, the system's priority is allocated to the headway setting and the speed changes accordingly. The system can be overridden at any time to guarantee that the driver can manually take control of the vehicle.

Despite the desirable positive contribution of the ACC to driving comfort (e.g. decrease in workload – Stanton et al., 1997) and road

* Corresponding author at: Chalmers University of Technology, Department of Applied Mechanics Department, Division of Vehicle Safety, Accident Prevention Group, Lindholmspiren 3, Lindholmen Science Park, 41756 Göteborg, Sweden. Tel.: +46 729427390.

E-mail addresses: giulio.piccinini@chalmers.se, giulio.piccinini@isec.universitas.pt (G.F. Bianchi Piccinini), cmr@fe.up.pt (C.M. Rodrigues), jml@isep.ipp.pt (M. Leitão), anabelasimoes@cigest.ensinus.pt (A. Simões).

http://dx.doi.org/10.1016/j.ssci.2014.09.008
0925-7535/

safety (e.g. reduction of rear-end accidents – Chira-Chavala and Yoo, 1994), the system presents several limitations that are caused by the limited scanning properties of the device detecting the vehicle in front (e.g., radar, sonar, stereoscopic camera-based) and by the finite braking capacity of the vehicle. Due to these limitations, critical situations may arise: the system may lose the lead vehicle in curves and may not detect small vehicles, such as motorbikes, vehicles that do not drive in the centre of the lane or vehicles in close quarters. In addition, the system does not react to slow-moving or stationary vehicles and may not work in city traffic, at intersections, on slippery surfaces, in poor visibility or in heavy rain. Although these limitations are often described in the vehicle owner's manual, a remarkable percentage of drivers do not read the manual, and those drivers who do read the manual, read approximately 50% of it (Mehlenbacher et al., 2002). This aspect is remarkable given that the reading of the owner's manual, together with the usage of the ACC, contributes to the shaping of the mental model of the system and of the trust in the system. Previous studies conducted on the topic showed that, even after the first usages of ACC, the mental model of the system might still be rudimentary (Larsson, 2012; Llaneras, 2006; Strand et al., 2011) and that excessive trust might be placed in the system (Dickie and Boyle, 2009).

1.2. Mental models

Broadly speaking, a mental model (or mental representation) is a dynamic representation or simulation of the world (Craik, 1943). In a more specific interaction with a system, a mental model can be described "as the mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states" (Rouse and Morris, 1986). Based on this definition, the mental model directly influences the interaction and the cooperation between the user and the system and is critical to the performance and operation of that system (Stanton and Young, 2000a). As a consequence, an incorrect mental model may cause an improper use of a device or a misunderstanding of the actions undertaken and of the information provided.

With regard to the specific use of the ACC system, the 'mental model' is an especially important concept given the system's limitations earlier mentioned. If the driver's mental model of the system is 'not good enough', the driver may not be aware of some of the limitations of the ACC system, and as a consequence, risky circumstances may originate (Stanton and Young, 2000b). For example, imagine the situation of a stationary vehicle on the path of the car equipped with ACC: in this case, despite the ACC can detect the stationary vehicle, the system will not brake (as a consequence of a design choice). If the driver's mental model of the ACC does not include this limitation of the system, the driver may not react in a timely manner to avoid a crash with the stationary vehicle. As a further example, if the driver's mental model of the system does not consider the limited braking capacity of the ACC, the user may believe that the system works in any driving condition and may not respond if an emergency stop is required.

The drivers' mental model of the ACC system has already been assessed in previous research (Beggiato and Krems, 2013; Kazi et al., 2007). Kazi et al. (2007) continuously measured the driver's conceptual model (mental model) of the ACC system for a group of drivers without previous experience with ACC during a period of 10 days. The authors found that in this short period of time, drivers exhibited an incorrect mental model of the system that differed from the designers' mental model of ACC and caused the drivers to confuse the ACC system with the Anti-Crash system. On the other hand, in a multi-trials study, Beggiato and Krems (2013) investigated how different preliminary information regarding the ACC system (correct, incomplete and incorrect information) can influence the driver's mental model of the system for participants without previous experience of ACC. The results demonstrated that the drivers' mental model of the ACC system changed based on the provided description and the working principle of the system. However, along with practice, the drivers' mental representation of the ACC system converged towards the correct mental model because the drivers experienced critical situations with the system (cut-in situations, queues, failure to recognise motorbikes).

Despite the well-established definition, the assessment of mental models represents a challenge for researchers because there is not an agreed measure of mental models (Rowe and Cooke, 1995). Up to now, various techniques have been used to assess mental models, including card sorting, questionnaires and task analysis (Cherri et al., 2004). As for the two studies cited above, Kazi et al. (2007) used conceptual models whereas Beggiato and Krems (2013) employed a questionnaire expressly designed for the study.

1.3. Trust

As reported in other studies (Boer and Hoedemaeker, 1998; Inagaki and Itoh, 2013; Rudin-Brown and Parker, 2004), the concept of mental model is strictly linked to the driver's trust in the system. In general, trust can be defined as an attitude resulting from knowledge, beliefs, emotions and other elements, which generates positive or negative expectations concerning the reactions of a system and the interaction with it (Cahour and Forzy, 2009). The calibration of trust is a fundamental aspect in determining the human usage of automation (Muir, 1987; Parasuraman and Riley, 1997). If the user/driver has a misconception regarding the working principle, the capacities or the limitations of a system, the driver's trust in the system may not be adequate and an inappropriate use of the system may derive (Dzindolet et al., 2003; Itoh, 2012; Lee and See, 2004; Stanton and Young, 2000a).

With respect to the impact of trust on the use of the ACC system, previous research has already been performed. Based on a study conducted in Sweden, a driver's excessive trust in the system could create expectations concerning the system's ability to brake autonomously in a scenario with a stationary queue (Nilsson, 1995). Rudin-Brown and Parker (2004) found that trust in ACC increased following exposure in the short-term period and it did not decrease even when drivers were exposed to a failure of the system. In a later paper, a driver's high trust in the ACC system was considered as the reason for the driver's more frequent use of the system and for the lower time headway to the preceding vehicle in the critical circumstance of a cut-in situation (Rajaonah et al., 2006). Finally, later research (Beggiato and Krems, 2013; Kazi et al., 2007) examined the evolution over time of the driver's trust in the ACC. In Kazi et al. (2007), drivers, without previous experience with ACC and who tested 'partially reliable' and 'unreliable at all' versions of the ACC, placed an inappropriate level of trust in the system. However, their trust did not increase over time, whereas the reliable group's trust in the system increased during the 10-day experiment. In Beggiato and Krems (2013), drivers who received different system descriptions (reliable, incomplete and incorrect) exhibited a different level of trust in the system before and after using the ACC over time. Contrary to Kazi et al. (2007), the drivers in the incorrect group did not rely excessively on the system, and their level of trust in the ACC changed over time.

1.4. Rationale for the study

The relevant impact of the driver's mental model of the ACC and of the driver's trust in the system on the proper and safe use of the