Applied Ergonomics 72 (2018) 37–47

Contents lists available at ScienceDirect

Applied Ergonomics

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

An interview study exploring Tesla drivers' behavioural adaptation

Rui Lin[a,b], Liang Ma[a], Wei Zhang[a,b,*]

[a] Department of Industrial Engineering, Tsinghua University, Beijing, 100084, China
[b] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, 100084, China

ARTICLE INFO

Keywords:
Automated driving
Partial automation system
Secondary task

ABSTRACT

Partially automated vehicles (PAVs) have been used in real-world environments for several years since the emergence of autonomous driving. It is important to understand the effects of partial automation systems (PAS) on the understanding of drivers and their behaviour during the first months of use. In order to adapt to new vehicle technology, drivers usually exhibit specific behaviours in this stage that are not intended by the developers, namely *behavioural adaptation.* The present study investigated the behavioural adaptations by early PAV adopters after short-term usage. A semi-structured interview was conducted among 20 Tesla drivers who had relatively high experience (one to five months) with Autopilot, and the interviews were synthesized to understand their behavioural adaptation, mental models, and trust during the period of use. The results showed that PAV drivers had a very positive attitude towards the PAS and drivers universally engaged in secondary tasks during automated driving. They also learned from their experiences to identify relatively safe usage conditions and they employed a safety margin to avoid exposure to excessively risky situations.

1. Introduction

The advanced driver assistance systems 'Combined Function Automation' (NHTSA et al., 2013) and 'Partial Automation' (SAE, 2014; Gasser and Westhoff, 2012) have been introduced onto the market to assist driving, where they simultaneously allow both longitudinal and lateral control. It is considered that autonomous driving systems have the potential to improve the wellbeing of drivers and increase safety by preventing driver errors on public roads (Stanton and Marsden, 1996; Driel and Arem, 2010; Doecke and Anderson, 2013).

However, a fatal accident in the USA was strongly associated with the misuse of a partial automation system (PAS) (NHTSA, 2017), and several non-fatal crashes have also been linked with a delayed reaction or misuse of this automation system (Tesla Motors Club, 2016a, 2016b). The behaviour of drivers when using a PAS might have caused these traffic accidents.

Under current PAS rules (Level 2 automation; see SAE, 2014), drivers are required to continuously monitor the system and be prepared to take over at any time in case the system reaches its technical limits or a malfunction occurs (Gasser et al., 2016). Thus, the driver's task has changed from active driving to supervising the PAS with occasional intervention.

In laboratory settings, researchers have found that driving with a PAS is a more difficult task for humans than manual control due to side effects caused by the PAS, such as decreased vigilance (Kaber and Endsley, 2004), skill degradation (Merat et al., 2014), overreliance or complacency (Beller et al., 2013; Helldin et al., 2013), or reduced situation awareness while engaging in a secondary task (de Winter et al., 2014). During manual driving, engaging in a secondary task takes the visual attention away from the forward roadway and it could increase the likelihood of a near-crash/crash (Simons-Morton et al., 2014). Klauer et al. (2006) found that glancing away for more than 2 s for any purpose could increase the near-crash/crash risk by at least two times compared with normal baseline driving.

In many PAS studies, drivers experienced automation systems for the first time over a short period of time (generally less than 30 min; Naujoks et al., 2015; Sibi et al., 2016; van den Beukel and van der Voort, 2017). During this short period, it is likely that drivers are not able to integrate the behavioural changes caused by the PAS into their normal behaviour (Wege et al., 2013). Therefore, it is important to explore the actual behaviour of drivers after interacting with the PAS for a relatively longer time period (one to five months).

1.1. Behavioural adaptation

During a certain period of interaction, in order to adapt to new vehicle technology, drivers usually exhibit specific behaviours that are regarded as behavioural adaptation (BA). BA mainly describes behaviours that are not intended by the initiators or developers of the change (OECD, 1990). Typically, the different forms of BA that have

* Corresponding author. Department of Industrial Engineering, Tsinghua University, Beijing, 100084, China.
E-mail address: zhangwei@tsinghua.edu.cn (W. Zhang).

https://doi.org/10.1016/j.apergo.2018.04.006
Received 5 July 2017; Received in revised form 16 April 2018; Accepted 17 April 2018

negative effects on safety are of most interest to road safety researchers and policy makers. It has been shown that most drivers need a period of about two weeks to learn how and when to use an in-vehicle system (Weinberger et al., 2001; Viti et al., 2008). Therefore, BA can be viewed in several stages (Manser et al., 2013; Wege et al., 2013) where the two main phases are the 'learning and appropriation phase' and the 'integration phase' (Cacciabue and Saad, 2008). Studies using laboratory simulators have mainly observed BA in the first phase of using adaptive cruise control (ACC) that partly automates longitudinal car control. They raised concerns about poorer lane discipline, sudden reactions to safety-critical events, increased speed, or decreased time headway (Nilsson, 1995; Dragutinovic et al., 2005; Young and Stanton, 2007). In general, these studies mainly demonstrated that driving safety was negatively influenced by the use of ACC for a limited period of time.

However, other studies have focused mainly on BA in the 'integration phase' using large field operational tests (FOTs) where the behaviour of experienced vehicle-technology drivers was recorded on real roads. FOT studies have shown that the potential for adverse BA was not as serious as that found in tests using simulators (Benmimoun et al., 2013), where the drivers exhibited particular self-regulatory behaviours such as keeping the system deactivated under dense traffic conditions (Pauwelussen and Feenstra, 2010).

Nevertheless, research has shown that the drivers of vehicles with ACC are more likely to engage in secondary tasks than non-ACC drivers, especially when they became familiar with this system (Malta et al., 2012; Bianchi Piccinini et al., 2012; Huth et al., 2012). Thus, the exploration of BA needs to focus more on the 'integration phase' (Patten, 2013).

The cognitive process that underlies these behaviours in the dynamic process has been explained by a qualitative model of the BA framework (Rudin-Brown, 2010; see Fig. 1). This model indicates that:

> '*Drivers who are more likely to trust a device are predicted to be more likely to change their mental model of the driving task. This change in the mental model would influence driving behaviour directly. Meanwhile, drivers' behaviour towards the vehicle-road system would, in turn, provide feedback to their level of trust.*'

In order to explore the BA of drivers in response to a PAS, the present study focused mainly on the mental model, trust, and BA associated with the PAS, and attempted to explain the formation of any observed BA under this framework.

1.2. Mental models

A mental model is defined as ' … a rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works, and why it works that way' (Carroll et al., 1987) when a user is interacting with a system. The information in the mental model has analogical relationships with the external world and it allows people to make successful predictions (Brewer, 2003). Mental models of the driving task are closely related to the situation awareness (Stanton and Young, 2005) and BA of drivers (Rudin-Brown, 2010; Smiley, 2000). Accidents often occur when a driver's inaccurate mental model does not match the actual road situation (Cafiso et al., 2007; Lamm et al., 1999). The mental model of vehicle technology reflects how a driver understands its function and limitations, which they can then employ to decide when and where to activate or deactivate the system (Boer and Hoedemaeker, 1998).

In the area of mental model studies related to ACC, Beggiato and Krems (2013) showed that both the initial information and practice can help drivers build mental models of ACC during its use. However, most drivers do not actually rely on the user manual to form their mental models, and thus their mental models are formed mainly based on their experience through use, which often makes them tend to overestimate the helpfulness of ACC (Jenness et al., 2008; Piccinini et al., 2013). Moreover, a strategy that relies on trial-and-error practice alone is considered insufficient for developing an appropriate ACC mental model (Beggiato and Krems, 2013). In reality, even experienced ACC users often fail to fully understand the functions and limitations of the technology, which may cause serious problems in the worst case (Bianchi Piccinini et al., 2015).

1.3. Trust

Trust is ' … the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability' (Lee and See, 2004). Trust in technology is 'a cognitive attitude towards the respective technology that changes over time' (Lee and See, 2004). Trust is often considered a by-product of the perceived accuracy of a mental model of the technology (Beggiato et al., 2015) and an intermediate variable of behaviour (Comte, 2000).

Similar to a mental model, pre-existing knowledge and experience may influence trust (Hoff and Bashir, 2015). In addition, aspects of the driver's personality such as confidence and locus of control can also influence trust (Rudin-Brown, 2010; Walker et al., 2016). Driving

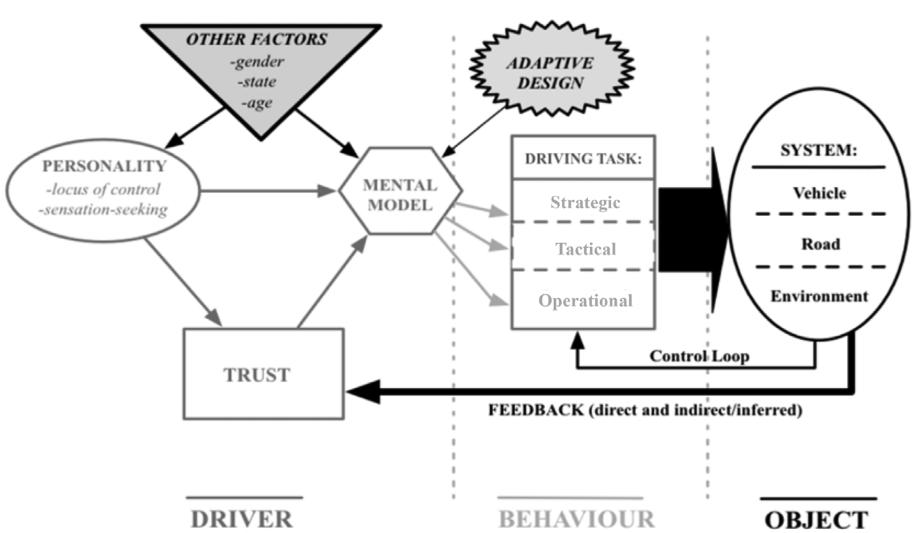

Fig. 1. Qualitative model of behavioural adaptation (Rudin-Brown, 2010).