Accident Analysis and Prevention 115 (2018) 202–208

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Psychosocial factors associated with intended use of automated vehicles: A simulated driving study

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ARTICLE INFO

Keywords:
Automated vehicles
Theory of Planned Behavior
Technology Acceptance Model
Trust in automation
Driving simulator

ABSTRACT

This study applied the Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) to assess drivers' intended use of automated vehicles (AVs) after undertaking a simulated driving task. In addition, this study explored the potential for trust to account for additional variance to the psychosocial factors in TPB and TAM. Seventy-four participants (51% female) aged between 25 and 64 years (M = 42.8, SD = 12.9) undertook a 20 min simulated experimental drive in which participants experienced periods of automated driving and manual control. A survey task followed. A hierarchical regression analysis revealed that TPB constructs; attitude toward the behavior, subjective norms, and perceived behavioral control, were significant predictors of intentions to use AV. In addition, there was partial support for the test of TAM, with ease of use (but not usefulness) predicting intended use of AV (SAE Level 3). Trust contributed variance to both models beyond TPB or TAM constructs. The findings provide an important insight into factors that might reflect intended use of vehicles that are primarily automated (longitudinal, lateral, and manoeuvre controls) but require and allow drivers to have periods of manual control.

1. Introduction

Automated vehicles (AVs) have the potential to reduce the significant number of crashes and associated crash-related injuries and fatalities on our roads. The SAE International Standard J3016 proposes six levels of automation, from no automation (Level 0) to full automation (Level 5). The focus of this paper is on conditional (Level 3) automation. For conditional (Level 3) automation, all safety critical features are automated. However, the driver is able to regain control of the vehicle at any time. Since 2017, 33 U.S. states have introduced legislation associated with AVs (National Conference of State Legislatures, 2018) and many other jurisdictions around the world similarly have considered legislation that suggests support and recognition of the potential of AVs. With the increasing advancements in automated capabilities of passenger vehicles, it is timely to examine drivers' intended use of this type of technology. Intentions is one factor which likely has important implications for the take up of AVs and thus the realisation of the benefits of such technology.

To date most studies which have examined drivers' intended use of conditional AVs have relied upon a descriptive text of a technical explanation of AV capabilities instead of tangible stimuli (e.g., see summary by Hulse et al., 2018). Given that technical explanations may be difficult to comprehend, or have a narrow or ambiguous focus, further research is required to evaluate drivers' responses to AVs in a more direct manner. A simulator study provides the potential for a 'mental model' of the AV experience based on interactions with a system (Körber et al., 2017). The current paper in part addresses the gap of limited information and experience from textual descriptions and explores drivers' intended use of a conditional AV (Level 3) building on established psychological theories.

As with other technology fields that examine responses toward emerging technologies, there is recognition of the value of parsimonious psychosocial models in explaining potential use. A theory provides a grounded framework from which to develop future efforts and using an established theory reduces the potential for a haphazard approach to understanding a phenomenon. The approach thus can identify factors that are potentially amenable to change, in contrast to factors such as demographics for example, that may not be modifiable. We focus on assessing intention as planned use of AVs and as expected future behavior. Such behavior is then theorised to result from socio-cognitive decisions and fulfilment of needs and requirements (Körber et al., 2017).

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https://doi.org/10.1016/j.aap.2018.03.021
Received 18 July 2017; Received in revised form 20 March 2018; Accepted 21 March 2018
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1.1. Theoretical models of technology acceptance

Psychosocial models, such as the Theory of Planned Behavior (TPB), have been used to explain many driving-related behaviors, including intentions to drive while drowsy (Lee et al., 2016) and cell phone use in distracted driving (Tian & Robinson, 2017). The TPB proposes that attitudes toward a behavior (ATB), subjective norms (SN), and perceived behavioral control (PBC) influence intentions, which subsequently influence behavior (Ajzen, 1991). The TPB posits that ATB reflect favorable or unfavorable evaluations or expectations about the outcomes of performing a specific behavior. Previous studies speculate that potential drivers may consider multiple expectations about outcomes, for example safety benefits, energy saving benefits, privacy costs (Woisetschläger, 2016). ATB is typically operationalized as a global construct in which a host of expectations could be considered to make the intended and specified behavior favourable, positive, good, and worth undertaking. ATB is thus largely a cognitive process potentially considering experiences and emotions that result from behavior. SN theoretically represents a belief that significant others (e.g., family or friends) would approve or disapprove of use. Madigan et al. (2016) found reporting that 'people around them think that they should use…' was correlated with use of a public 12-person automated electric shuttle bus. Finally, PBC reflects the ease or difficulty of use, it may reflect confidence to use an automated feature or that use is within the individual's skill set or control. Thus, TPB is a parsimonious theory that posits favourable expectations, perceived approval from significant others, and perceived confidence to use will predict intended AV use.

The Technology Acceptance Model (TAM) (Davis, 1989) is also a parsimonious theory and it has been applied to evaluate technology acceptance in a variety of fields, including in passenger vehicles (e.g., acceptance of in-vehicle navigation systems; Chen and Chen, 2011). Of note, the TAM approach uses the term acceptance instead of intention however the constructs are defined and operationalized in the same way. The TAM postulates that perceived ease of use and perceived usefulness predict intentions to use a system. Perceived ease of use (PEofU) reflects the effort or the degree to which the individual believes using the system will reduce effort (Rahman et al., 2017) thus perhaps that the driving task reduces in effort with AV and/or that AV requires little effort to use. Perceived Usefulness (PU) in contrast reflects the degree to which the system is perceived as helpful and enhances performance (De Angelis et al., 2017) and thus perhaps reflects a belief that AV would enhance driving performance or transportation. Psychosocial models which address such factors may offer extra information in addition to current research which has more typically asked whether drivers' have liked (or have not liked) AV technology or examined demographic factors associated with intended use (Kyriakidis et al., 2015).

Limited research has assessed perception of AVs in accordance with the theoretical constructs of TPB and TAM. One study focused on fully AV (Level 5) reported that there were significant strong positive associations between attitudes and intentions to use and intentions to buy a fully AV (Payre et al., 2014). These authors reported that the construct they termed attitude (i.e. consideration of fully automated vehicles as unpleasant/pleasant, useless/useful, dangerous/sure) was a significant predictor of intentions to use AVs, along with sensation seeking and a construct labelled, contextual acceptability. Their measure of contextual acceptability included items around: preference for control, beliefs about safety, and preference for use when bored or with passengers.

Further, Rahman et al (2017) examined the utility of the TPB and TAM constructs for intentions to use advanced driver assistance system (ADAS) technologies. Two approaches were used to collect data in Rahman et al.'s study (2017), one of which involved participants undertaking a simulated driving task (open cab mock-up, n = 43). For this task participants were asked to engage the advanced driver assistance system after a period of manually operating the vehicle. Rahman et al. (2017) found constructs of ATB, SN, and PBC accounted for 80% of the variance in intentions to use ADAS, and the TAM constructs accounted for 82% of the variance in intentions. These findings suggest that the TPB and TAM are suitable models to use to assess drivers' acceptance of AV technologies. The current study expands upon the work of Rahman et al. (2017) by examining the utility of the TPB and TAM for intentions to use a Level 3 conditional AV (as opposed to a Level 2 vehicle) and incorporating automated vehicle control with periods of transfer and manual control by the driver (as opposed to no periods of transfer). Given that automation transition to manual (and vice versa) may influence one's intentions to use conditional AVs, more research is required to assess the TPB and TAM constructs after drivers' have been exposed to these additional automated functions.

1.2. Strengthening TPB and TAM

In addition to the TPB and TAM constructs, trust is another construct which may influence drivers' intentions to use AV technology. While it is acknowledged that trust is a multi-faceted concept and that multiple definitions of trust in automation exist (see: Muir, 1994; Walker et al., 2016), in the current study trust in automation was referred to as the drivers' perception of the reliability of the conditional AV. Lee and See's (2004, p.51) definition is commonly used and reflects, "the attitudes that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability." Thus it potentially reflects a belief that AV will help drivers' meet their driving goals despite the driver perceiving uncertainty. As suggested by Körber et al. (2017) this definition can incorporate characteristics of the system (e.g. predictability) and of the driver (e.g. propensity to trust). Trust in automation is an important factor in determining whether a driver will adopt and rely upon automation (Choi and Ji, 2015; Hoff and Bashir, 2015). For example, Choi and Ji (2015) surveyed 552 drivers and found a significant moderate positive relationship between trust and intention to adopt AVs. Further, there has been a recent emergence of research which has highlighted that trust may be an important factor in the acceptance of various levels of AV (corresponding to when the technology is introduced) (e.g., Gold et al., 2015).

Good cooperation with automated systems ensure drivers get the best and safest options from the technology (Hergeth et al., 2017) and it has been theorised and shown that trust can underpin cooperation (Helldin et al., 2013). The concept of trust reflects predictability and understanding thus the simulator provides a consistent interface to assess a construct such as trust. Of note, Rahman et al. (2017) found those using ADAS in a simulator (open cab mock-up) had higher ratings of intention than their survey sample (responding to a textual definition). The value in understanding perceived trust in the system may reside in the way in which information is presented as well as conveyed to those who may use such conditional AV systems (Beggiato et al., 2015; Hergeth et al., 2017). We consider how relevant trust is in relation to other psychosocial factors and thus the work has potential benefit in considering how to frame messages about AV systems to promote use of the vehicles as designed by the manufacture. The current research expands upon previous research by examining if trust is associated with behavioral intentions to use AV, above and beyond the TPB constructs of ATB, SN, and PBC. In addition, we explore the potential added variance of trust to the TAM.

A much cited benefit to AV is to lessen workload of the driving task, with particular groups who may find driving tasks more demanding (including temporary impairment) among those likely to gain the most from the introduction of AVs. For example, vehicles with more automated features (e.g., SAE Levels 3 and above) are suggested to have benefits that enable drivers to undertake secondary non-driving tasks. Given the potential benefits to a reduced driving workload; driving workload may be associated with acceptance and intended use of AV. We provide a brief self-report assessment of workload in the context of TPB and TAM. While studies have rarely incorporated a workload

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