Assessing the utility of TAM, TPB, and UTAUT for advanced driver assistance systems

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ABSTRACT

Advanced Driver Assistance Systems (ADAS) are intended to enhance driver performance and improve transportation safety. The potential benefits of these technologies, such as reduction in number of crashes, enhancing driver comfort or convenience, decreasing environmental impact, etc., have been acknowledged by transportation safety researchers and federal transportation agencies. Although these systems afford safety advantages, they may also challenge the traditional role of drivers in operating vehicles. Driver acceptance, therefore, is essential for the implementation of these systems into the transportation system. Recognizing the need for research into the factors affecting driver acceptance, this study assessed the utility of the Technology Acceptance Model (TAM), the Theory of Planned Behavior (TPB), and the Unified Theory of Acceptance and Use of Technology (UTAUT) for modelling driver acceptance in terms of Behavioral Intention to use an ADAS. Each of these models propose a set of factors that influence acceptance of a technology. Data collection was done using two approaches: a driving simulator approach and an online survey approach. In both approaches, participants interacted with either a fatigue monitoring system or an adaptive cruise control system combined with a lane-keeping system. Based on their experience, participants responded to several survey questions to indicate their attitude toward using the ADAS and their perception of its usefulness, usability, etc. A sample of 430 surveys were collected for this study. Results found that all the models (TAM, TPB, and UTAUT) can explain driver acceptance with their proposed sets of factors, each explaining 71% or more of the variability in Behavioral Intention. Among the models, TAM was found to perform the best in modelling driver acceptance followed by TPB. The findings of this study confirm that these models can be applied to ADAS technologies and that they provide a basis for understanding driver acceptance.

1. Introduction

The transportation landscape is changing rapidly. The introduction of in-vehicle technologies, automated vehicles, and advanced road infrastructure will undoubtedly have a significant impact on the safety and efficiency of transportation systems. Although automation in the transportation system has the potential to significantly reduce the number of vehicle crashes and the economic burden associated with them (Fagnant and Kockelman, 2015; Manyika et al., 2013; MacCubbin et al., 2008), this is only true if drivers recognize the usefulness of these technologies and integrate them into their travel habits. Hence, driver acceptance is a precondition for successful implementation of vehicle automation (Najm et al., 2006). Although Advanced Driver Assistance Systems (ADAS) include the gamut of technology and automation, the current paper focuses on driver acceptance of lower level and currently available in-vehicle assistive technologies. To be more specific, this paper explores how driver acceptance of these technologies can be assessed with theories of human behavior that have been adopted and validated for technology acceptance.

In-vehicle assistive technologies have been categorized as Advanced Driver Assistance Systems (ADAS) (Paul, Chauhan, Srivastava, & Baruah, 2016; Hummel, Kühn, Bende, & Lang, 2011), Intelligent Transport Systems (ITS) (Dimitrakopoulos and Demestichas, 2010; Beresford and Bacon, 2006), and semi-autonomous driving systems (Kala and Warwick, 2015), among others. These categories vary according to level of automation. To reduce confusion, this paper will refer to in-vehicle assistive technologies as ADAS, defined as technologies which can assist drivers with relevant information (for example, a lane departure warning system) and can assume control over a single vehicle function (for example, an adaptive cruise control system) or a combined vehicle function (for example, an adaptive cruise control system combined with a lane centering system); these are labeled as...
vehicle automation levels 0, 1, and 2 by NHTSA (2013).

Ensuring safety for drivers and other road users and providing convenience for drivers has motivated the development of new ADAS (Trimble, Bishop, Morgan, & Blanco, 2014). ADAS technology has many advantages, such as providing drivers with important information, relieving drivers by occasionally taking over parts of the driving task, and sometimes providing added control to aid drivers in critical situations. These advantages could potentially augment driver performance and reduce crash-related accidents. Based on ADAS potential, initial driver reaction has been reported to be very positive (Ferguson, Wells, & Kirley, 2007; Braitman, McCartt, Zuby, & Singer, 2010; Eichelberger and McCartt, 2014; Cicchino et al., 2015; Cicchino and McCartt, 2015). However, these technologies will not achieve their potential if drivers do not move beyond an initial interest to actually accepting them, using them appropriately in traffic. Thus, the study of driver acceptance of new ADAS is crucial in the early stages of development and implementation.

Driver acceptance of ADAS can be defined as the reaction of drivers when they are exposed to an in-vehicle technology and their willingness to adopt the technology while driving. Although there is a general understanding of the term among researchers, the research on driver acceptance has experienced varying attempts at defining, modelling, and measuring acceptance (Regan, Mitsopoulos, Haworth, & Young, 2002; Adell, Varhelyi, & Nilsson, 2014). Acceptance is a multi-faceted concept and researchers have focused on different aspects of it in their research. Despite many differences in how researchers have studied driver acceptance, there is common ground in the application of models of human behavior and theories of technology acceptance initially developed outside the domain of driving (e.g., Technology Acceptance Model, Theory of Planned Behavior). These models provide a theoretical framework to define, model, and measure driver acceptance. Recognizing the importance of these models in the research on driver acceptance, this study set out to evaluate and compare the predictive ability of these models in the context of ADAS.

1.1. Theories of human behavior and technology acceptance

For many years, researchers have adopted theories of human behavior to study technology acceptance (cited in Legris, Ingham, & Collerette, 2003; Davis, 1985; Venkatesh et al., 2003). Among these approaches, the Technology Acceptance Model (TAM) (Davis, 1985; Davis, 1989), the Theory of Planned Behavior (TPB) (Ajzen, 1991), and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) were found, in an earlier review, to be the most frequently adopted by researchers in modelling driver acceptance (Rahman, 2016). TPB was developed to explain human behavior in general, whereas TAM and UTAUT were specifically developed to explain technology acceptance. These theories propose several factors that affect acceptance of a technology, with Behavioral Intention (to use a technology) and Actual Behavior (actual use of the technology) as measures of acceptance.

The Technology Acceptance Model (TAM), built on the Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 1975), proposes two components of Behavioral Intention: Attitude towards Behavior and Perceived Usefulness (Davis, 1985, Fig. 1a). TAM posits that with positive Attitude and high Perceived Usefulness, users are more likely to have high intention to use a technology and eventually use it. Attitude is defined as the emotional state toward using a technology (Fishbein and Ajzen, 1975) and, according to TAM, is influenced by the beliefs of Perceived Usefulness and Perceived Ease of Use (see Table 1 for definitions and model components).

### Table 1
Summary of the theoretical models of technology acceptance.

<table>
<thead>
<tr>
<th>Theory</th>
<th>Components of Behavioral Intention</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology Acceptance Model (TAM)</td>
<td>Attitude Toward Behavior</td>
<td>“An individual’s positive or negative feelings (evaluative affect) about performing the target behavior” (Fishbein and Ajzen, 1975, p. 216).</td>
</tr>
<tr>
<td></td>
<td>Perceived Usefulness</td>
<td>“The degree to which a person believes that using a particular system would enhance his or her job performance” (Davis, 1989, p. 320).</td>
</tr>
<tr>
<td></td>
<td>Perceived Ease of Use</td>
<td>“The degree to which a person believes that using a particular system would be free of effort” (Davis, 1989, p. 320).</td>
</tr>
<tr>
<td>Theory of Planned Behavior (TPB)</td>
<td>Attitude Toward Behavior</td>
<td>Same as in TAM</td>
</tr>
<tr>
<td></td>
<td>Subjective Norm</td>
<td>“The person’s perception that most people who are important to him think he should or should not perform the behavior in question” (Fishbein and Ajzen, 1975, p. 302).</td>
</tr>
<tr>
<td>Unified Theory of Acceptance and Use of Technology (UTAUT)</td>
<td>Perceived Behavioral Control</td>
<td>“The perceived ease or difficulty of performing the behavior” (Ajzen, 1991, p. 188).</td>
</tr>
<tr>
<td></td>
<td>Performance Expectancy</td>
<td>“The degree to which an individual believes that using the system will help him or her to attain gains in job performance” (Venkatesh et al., 2003, p. 447).</td>
</tr>
<tr>
<td></td>
<td>Effort Expectancy</td>
<td>“The degree of ease associated with the use of the system” (Venkatesh et al., 2003, p. 450).</td>
</tr>
<tr>
<td></td>
<td>Social Influence</td>
<td>“The degree to which an individual perceives that important others believe he or she should use the new system” (Venkatesh et al., 2003, p. 451).</td>
</tr>
<tr>
<td></td>
<td>Facilitating Conditions</td>
<td>“The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system” (Venkatesh et al., 2003, p. 455).</td>
</tr>
</tbody>
</table>

**Fig. 1.** Technology acceptance models.

Perceived Usefulness (PU) — Perceived Ease of Use (PEOU) — Attitude Toward Behavior (A) — Behavioral Intention (BI) — Actual System Use

a: TAM (Davis, 1985) (Figure Source: Davis, Bagozzi, & Warshaw, 1989)
Another version of TAM is available that does not consider Attitude as an influencing factor, but rather proposes Perceived Usefulness and Perceived Ease of Use to have direct and positive effects on Behavioral Intention (Davis, 1989, Fig. 1b). Both versions of TAM also propose a mediation of the effect of Perceived Ease of Use by Perceived Usefulness.

The Theory of Planned Behavior (TPB) (Ajzen, 1991), which is also built on the Theory of Reasoned Action (TRA), extended TRA to improve its predictive capability. TPB includes three components of Behavioral Intention: Attitude, Subjective Norms, and Perceived Behavioral Control (defined in Table 1). It posits that positive Attitude and favorable normative and volition control beliefs will create positive Behavioral Intention to use a technology (Fig. 1c). In TPB, besides the direct influence of Behavioral Intention on actual behavior, Perceived Behavioral Control indirectly affects Actual Use. The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), on the other hand, proposes four components of Behavioral Intention and Actual Behavior: Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions (defined in Table 1). UTAUT posits that Performance Expectancy, Effort Expectancy, and Social Influence positively influence Behavioral Intention; and Behavioral Intention and Facilitating Conditions positively influence Actual Behavior. UTAUT also proposes four moderating factors: age, gender, experience, and voluntariness. The moderating effects in UTAUT are illustrated in Fig. 1d.

There have been several attempts to model driver acceptance of in-vehicle technology using TAM, TPB, and UTAUT. A subset of these attempts are summarized in Table 2. From the table it is apparent that most of the studies have considered TAM, TPB, and UTAUT factors with the inclusion of one or more new factors specific to ADAS technology, as an attempt to capture the unique characteristics of these technologies. Several of these studies adopted TAM (either of the two versions) to model driver acceptance. For example, Meschtscherjakov, Wilfinger, Scherndl, and Tscheligi (2009) investigated the effect of Attitude toward car technology with six other factors and found a significant effect of Attitude on Behavioral Intention. Chen and Chen (2011) and Park and Kim (2014) adopted the TAM model (Davis, 1985) to study acceptance of vehicle navigation systems. Both studies reported that favorable Attitude leads to positive Behavioral Intention to use a navigation system. On the other hand, only Park and Kim (2014) reported Perceived Usefulness as a significant predictor of Behavioral Intention. Roberts, Ghazizadeh, and Lee (2012) used a driving simulator approach to study driver acceptance of two in-vehicle driver assistance technologies with an augmented TAM model (Davis, 1989). The authors hypothesized an effect of Unobtrusiveness on Behavioral Intention in addition to the effects of Perceived Usefulness and Perceived Ease of Use. However, only the effects of Perceived Usefulness and Perceived Ease of Use were found to be significant. Similar attempts to augment the TAM model (Davis, 1989) were also found in the literature (Xu et al., 2010; Ghazizadeh et al., 2012b). In contrast to the popularity of TAM in driver acceptance research, a limited number of studies adopted TPB and UTAUT to model driver acceptance. Larue, Rakotonirainy, Haworth, and Darvell (2015) applied and compared TAM (Davis, 1989) and TPB for assessing driver acceptance of an intelligent transport system in the context of railway level crossings. The authors reported Perceived Usefulness, Attitude, and Subjective Norms to be significant predictors of Behavioral Intention. The authors also reported better performance by TPB (Adjusted $R^2 = 0.66$) compared to TAM (Adjusted $R^2 = 0.54$). Adell (2010) adopted UTAUT and found that Performance Expectancy and Social Influence positively influence Behavioral Intention to use an ADAS. A few other studies (Osswald, Wurhofer, Tröstler, Beck, & Tscheligi, 2012; Henzler, Boller, Buchholz, & Dietmeyer, 2015; Kervick, Hogan, O’Hora, & Sarma, 2015) used the factors proposed by UTAUT to develop new models of driver acceptance.

### 1.2. Objectives of the study

Modelling of driver acceptance is necessary to understand how driver acceptance is influenced by different factors and how it evolves over time. The intention of this study is to assess the utility of TAM, TPB, and UTAUT for modelling driver acceptance of ADAS. Even though these models provide a theoretical framework for assessing acceptance of a technology, their use in modelling driver acceptance of ADAS has been very limited. To the best of our knowledge, no previous study has compared the efficiency of these models in the context of driver acceptance of ADAS. In the literature, TAM (both versions), TPB, and UTAUT have been proposed as models for explaining user acceptance in terms of Behavioral Intention and Actual Use. This study used Behavioral Intention as the only measure of acceptance, and tested all the relationships proposed in these models in the context of driver acceptance of ADAS, comparing their efficiency. The postulates that were tested in this study are given below:

#### 1.2.1. TAM (Davis, 1985)

1. Attitude toward Behavior (A) and Perceived Usefulness (PU) are significant predictors of Behavioral Intention (BI) (model: $BI = A + PU$).
2. Attitude toward Behavior (A) mediates the effect of PU on BI, however the mediation is not a complete mediation. In other words, PU significantly affects BI, above and beyond A.
3. Perceived Usefulness (PU) and Perceived Ease of Use (PEoU) are significant predictors of Attitude toward Behavior (A) (model: $A = PU + PEoU$).
4. Perceived Usefulness (PU) mediates the effect of PEoU on A; however, the mediation is not a complete mediation. In other words, PEoU significantly affects A, above and beyond PU.

#### 1.2.2. TAM (Davis, 1989)

1. Perceived Usefulness (PU) and Perceived Ease of Use (PEoU) are significant predictors of Behavioral Intention (BI) (model: $BI = PU + PEoU$).
2. Perceived Usefulness (PU) mediates the effect of PEoU on BI; however, the mediation is not a complete mediation. In other words, PEoU significantly affects BI, above and beyond PU.

#### 1.2.3. TPB

1. Attitude toward Behavior (A), Subjective Norms (SN), and Perceived Behavioral Control (PBC) are significant predictors of Behavioral Intention (BI) (model: $BI = A + SN + PBC$).

#### 1.2.4. UTAUT

1. Performance Expectancy (PE), Effort Expectancy (EE), and Social
Influence (SI) are significant predictors of Behavioral Intention (BI) (model: BI = PE + EE + SI).
2. Gender moderates the effects of PE, EE, and SI on BI.
3. Age moderates the effects of PE, EE, and SI on BI.
4. Experience moderates the effects of EE and SI on BI.

The study employed mixed methods; two approaches were used to collect driver acceptance data: an online survey approach and a driver-in-the-loop simulator approach. The driving simulator approach allowed researchers to provide participants with hands-on experience in using an ADAS while driving, and the online survey allowed researchers to collect a large sample of driver acceptance data using a narrative scenario-based approach.

2. Materials and methods

2.1. Survey approach

2.1.1. Participants

400 participants took part in the online survey. Of those, 13 participants missed one or both of the check questions included in the survey and hence were removed from the final dataset, leaving 387 (202 male and 185 female) samples. The participants were 19–73 (M = 35.6 and SD = 11.0) years old. Almost half of the participants (190 participants) read the description of system 1 and the rest (197 participants) read the description of system 2 (see Section 2.1.2). Of the 387 participants, 60.98% were college graduates or higher, and all were licensed drivers.

2.1.2. Survey design and study materials

Borrowing from literature on the Theory of Planned Behavior (e.g., Ajzen, 1991; Elliott et al., 2005; Evans and Norman, 1998, 2003; Holland and Hill, 2007) and from recent studies regarding ADAS acceptance (Lesch, n.d.; Rodel et al., 2014), a scenario-based survey approach was utilized to introduce ADAS technologies to participants and to gather responses on acceptance. Two ADAS technologies were selected for the purpose of this study, one system relieves drivers by taking over parts of the driving task (System 1, see Appendix B for description) and the other system monitors driver fatigue level and alerts drivers to make sure that the participants were attentive to the survey, two check questions were included that instructed them to provide a specific response. Furthermore, 5 out of the 30 survey items were reverse scaled.

2.2. Driving simulator approach

2.2.1. Participants

A total of 48 participants were recruited from the population of greater Boston, MA area for the study. However, the data from 5 participants had to be removed due to equipment failure during the experimental session. Hence, the sample size for the driving simulator approach was 43 (20 males and 23 females, aged 21–57 years with M = 40.9, SD = 12.1). All simulator participants had a valid US driver’s license, were native or fluent English speakers, had normal or corrected-to-normal visual acuity (min. 20/40), normal color vision, and no self-reported hearing difficulties.

2.2.2. Simulated ADAS and driving scenario

In this approach, participants experienced an ADAS in a driving simulator and, based on their experience, answered several survey questions. The driving simulator that was used for this study was a fixed-base simulator that consists of an open-cab vehicle mock up, including accelerator and brake pedals, steering wheel, dashboard, instrument panel, and center console. The driving environments were presented on five 46-inch widescreen LCD displays which, from the driver’s eye point, subtended 200° of forward visual angle. The various driving environments and traffic scenarios were generated using RTI SimCreator and SimVista software and the vehicle automation was coordinated via the SimDriver software module (Realtime Technologies Inc., Royal Oak, MI).

For the purpose of this study, a level 2 (NHTSA, 2013) ADAS was simulated which fully controlled the vehicle under a variety of traffic and road situations, including longitudinal and lateral control of the vehicle. For longitudinal control, the preferred speed and headway clearances (e.g., Adaptive Cruise Control) were preset. For lateral control, the system would keep the vehicle at or near the center of the lane, on straight sections as well as in curves. Whenever there was a deviation from the preferred states, the system would make corrective inputs (e.g., speed up or slow down; steer towards the lane center).

2.2.3. Procedure

Prior to the experimental session, participants were screened via online and phone surveys for the minimum study requirements and for susceptibility to simulator sickness. At the start of the session, drivers completed an informed consent form. Vision was tested with a Titmus Optical Inc., Chester, VA), and then the drivers completed a short demographic survey. Following the completion of the questionnaires, participants were introduced to the driving simulator and given a practice trial to acclimatize to the control dynamics. They were monitored for signs of simulator sickness throughout. Following the completion of the training, participants read about the capability of the simulated ADAS which was the same as the description of System 1 (see Appendix B) in the survey approach. The study procedure is illustrated in Fig. 2.
The study consisted of a single experimental block aimed at exposing drivers to the ADAS and how it operates under routine situations. The block lasted approximately 8–10 min and involved a variety of traffic situations. Drivers began on a feeder road and were instructed to merge onto a two-lane highway. Once they had done so, they were asked to engage the ADAS via a button mounted on the steering wheel and to allow the ADAS system to control the driving for the duration of the driving block. While on the highway, the ADAS reacted intelligently to other proximal vehicles, changed speeds and correctly guided the vehicle through curves. Approximately halfway through the block, the highway merged onto a light industrial road that included several traffic lights. The ADAS continued to maintain appropriate spacing and position in this section and adhered to the traffic light status (i.e., applied brakes for yellow/red lights and drove again when signal turned green). The scenario simulated routine operational conditions and did not include any system failures or conditions that exceeded the tolerances of the ADAS. After the driving block, drivers were given the survey. The survey items used to measure the factors of the models were the same as in the online survey, except there were no check questions for the simulator study.

2.3. Data processing and analysis

The two datasets (from the survey study and the simulator study) were merged for analysis in order to increase the power of the tests. As a result, the sample size for the study was 430 (43 from the simulator study and 387 from the online survey study). In the merged dataset, data sources were separated using two new variables, data-type (coded as 0 for simulator data and 1 for online survey data) and system-type (coded as 0 for system 1 of the online survey and the simulated system, and 1 for system 2 in online survey). The effects of these variables were controlled in each data analysis method.

Following an assessment of the internal consistency of the scales, regression analyses were used to test the postulates proposed in TAM, TPB, and UTAUT. Statistical analyses were carried out in IBM SPSS (version 23). The steps of the data analysis are explained below in greater detail.

2.3.1. Internal consistency of the scales

The internal consistency of each scale was tested with Cronbach’s alpha. If the \( \alpha \) for a certain scale was found to be less than 0.70, bivariate correlations between each pair of scale items were evaluated to identify and remove the item(s) which had contributed to the low reliability. If removing the item(s) did not yield a value greater than 0.70 for \( \alpha \), the authors used the scale as it was intended.

2.3.2. Multiple linear regression analyses

Several individual regression analyses of the factors from TAM, TPB, and UTAUT were done to assess the predictive ability of the models. Before running regression analyses, scatter plots (BI vs the predictor variables) were drawn to check the linearity assumption. To check for the validity of other assumptions, scatter plots for residuals vs predictor variables, residuals vs fitted values, and Q-Q plots were evaluated. To compare the efficiency of each model for explaining the variance in driver acceptance of ADAS, Hotelling’s \( t \)-test for non-independent correlations was done. To test mediation, the procedure explained by Baron and Kenny (1986) and Kenny, Kashy, and Bolger (1998) was applied. This procedure involved performing three regression analyses for each mediation effect: first, the dependent variable was regressed on the independent variable; second, (if the relationship from step 1 was
found to be statistically significant, then) the independent variable was regressed on the mediator; and third, (if the relationship from step 2 was found to be statistically significant, then) the dependent variable was regressed on the mediator and on the independent variable. If, in the third step, an effect of the independent variable on the dependent variable was not observed (i.e., a non-significant regression coefficient), a complete mediation was found to be present, meaning that the mediator completely accounted for the relationship between the independent and dependent variables. If the effect of the independent variable was not zero in step 3, yet still significantly smaller than the effect found in step 1, the mediation was partial. To test moderation, the procedure explained by Frazier, Tix, and Baron (2004) was applied. In this procedure, the predictor and the moderator variables were standardized and then multiplied together in order to calculate the interaction term. Testing for a moderation effect involved a hierarchical regression technique. In the first step, the outcome variable was

<table>
<thead>
<tr>
<th>Study</th>
<th>Technology Tested</th>
<th>Equipment/Type of Study</th>
<th>Sample Size</th>
<th>Model(s)/Postulate(s) Tested</th>
<th>Effects Found</th>
<th>( R^2 )/Adj. ( R^2 )</th>
<th>Statistical Methods Used*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meschtscherjakov et al. (2009)</td>
<td>EcoMatic, EcoPedal, EcoSpeedometer, EcoDisplay, and EcoAdvisor (all of these ADAS provide real-time fuel-efficient driving guidance)</td>
<td>Online survey</td>
<td>57</td>
<td>BI = Age, Gender, Driving Frequency, General Attitude toward Car Technology, Possible Disturbance, Safety Risk, Perceived Suitability of the System</td>
<td>General Attitude toward Car Technology, Possible Disturbance, Perceived Suitability of the System</td>
<td>0.68 (for EcoPedal) 0.67 (for EcoSpeedometer)</td>
<td>ANOVA, Linear Regression Analysis</td>
</tr>
<tr>
<td>Adell (2010)</td>
<td>SASPENCE (assists in keeping safe speed and safe distance)</td>
<td>Naturalistic Study</td>
<td>38</td>
<td>UTAUT: BI = PE + EE + SI</td>
<td>PE, SI</td>
<td>0.20</td>
<td>Factor Analysis, Linear Regression Analysis</td>
</tr>
<tr>
<td>Chen and Chen (2011)</td>
<td>In-vehicle GPS</td>
<td>Face-to-face survey</td>
<td>251</td>
<td>BI = A + PU + Perceived Enjoyment (Enj.); A =PU + PEoU + Enj. PU = PEoU</td>
<td>PEoU, Enj.</td>
<td>0.52</td>
<td>Hierarchical Linear Regression Analysis</td>
</tr>
<tr>
<td>Ghazizadeh et al. (2012b)</td>
<td>An on-board monitoring system (provides auditory and visual forward collision warning, lane departure warning, and driver behavior warning)</td>
<td>Survey</td>
<td>34</td>
<td>BI = PU + PEoU + Trust; Trust = PU + PEoU; PU = PEoU</td>
<td>PU, Trust</td>
<td>0.65</td>
<td>Hierarchical Linear Regression Analysis</td>
</tr>
<tr>
<td>Osxwald et al. (2012)</td>
<td>In-car text input system</td>
<td>Driving simulator</td>
<td>21</td>
<td>BI = A + PE + EE + SI + Anxiety + Perceived Safety + Self Efficacy (Proposed)</td>
<td>No statistical analysis of the effects was done</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Roberts et al. (2012)</td>
<td>A real-time (provides visual and auditory warnings) and a post-drive distraction mitigation system.</td>
<td>Driving simulator</td>
<td>36</td>
<td>BI = PU + PEoU + Unobtrusiveness</td>
<td>PU and PEoU</td>
<td>0.50</td>
<td>Hierarchical Linear Regression Analysis</td>
</tr>
<tr>
<td>Park and Kim (2014)</td>
<td>Navigation system</td>
<td>Online survey</td>
<td>1181</td>
<td>BI = PU; BI = A; A = PU</td>
<td>PU and A are significant predictors of BI</td>
<td>-</td>
<td>Structural Equation Modeling</td>
</tr>
<tr>
<td>Rodel et al. (2014)</td>
<td>Navigation system, cruise control, automatic transmission, parking assist, automatic parking system, Collision Avoidance System, Adaptive Cruise Control, Blind Spot Detection.</td>
<td>Scenario-based online survey</td>
<td>336</td>
<td>BI, A, PEoU, PBC (among other factors) are affected by the level of autonomy</td>
<td>No association between BI and A was inferred</td>
<td>-</td>
<td>Friedman Test, Kruskal Wallis Test</td>
</tr>
<tr>
<td>Henzler et al. (2015)</td>
<td>Ecological Driver Assistance System (provides eco-driving recommendations)</td>
<td>Naturalistic study</td>
<td>24</td>
<td>BI = PE + EE</td>
<td>No statistical analysis of the effects was done</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Kervick et al. (2015)</td>
<td>A smartphone driver support system (provides information on vehicle speed, headway distance etc. and warns driver if the headway distance is unsafe)</td>
<td>Online survey</td>
<td>333</td>
<td>BI = Perceived Gains + Perceived Risks + SI + Usability</td>
<td>Perceived Gains, SI</td>
<td>0.73</td>
<td>Factor Analysis, Structural Equation Modeling</td>
</tr>
<tr>
<td>Larue et al. (2015)</td>
<td>Warning system (warns drivers of an approaching train or a congestion at a railway crossing and provides expected action)</td>
<td>Driving simulator</td>
<td>58</td>
<td>TAM: BI = PU + PEoU; TPB: BI = A + SN + PBC</td>
<td>PU, A, SN</td>
<td>0.54 0.66</td>
<td>Generalized Linear Mixed Model (GLMM) Analysis</td>
</tr>
</tbody>
</table>

*Most of the studies tested the reliability of the scales based on Chronbach’s alpha.

regressed on the predictor and the moderator. In the next step, the interaction term entered the regression model. If the interaction term was found to be significant, moderation was present.

3. Results

3.1. Reliability of scales and descriptive statistics

The internal consistency of the scales was found to be high for most of the scales, with a Cronbach’s alpha (α) of 0.7 or more (Table 3). Only the SN and SI scales showed poor reliability (α = 0.48). Both of these scales used the same survey items (items 18 and 19, Appendix A). As the scales had only two items and the use of a single-item scale could be problematic, it was not possible to evaluate bi-variate correlation to identify and remove any items. Hence, the authors used the scales as they were intended. The means and the standard derivations of the scales are summarized in Table 3. The results revealed that most participants had a very low familiarity with ADAS as either described or scales are summarized in Table 3. The results revealed that most participants had a very low familiarity with ADAS as either described or scales used the same survey items (items 18 and 19, Appendix A). As

<table>
<thead>
<tr>
<th>Factors</th>
<th>Mean</th>
<th>SD</th>
<th>BI</th>
<th>A</th>
<th>PU</th>
<th>PEoU</th>
<th>SN</th>
<th>PBC</th>
<th>PE</th>
<th>EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI</td>
<td>4.69</td>
<td>1.59</td>
<td>0.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>5.04</td>
<td>1.30</td>
<td>0.89**</td>
<td>0.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PU</td>
<td>4.95</td>
<td>1.33</td>
<td>0.85**</td>
<td>0.88**</td>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEoU</td>
<td>5.41</td>
<td>1.02</td>
<td>0.42**</td>
<td>0.49**</td>
<td>0.36**</td>
<td>0.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SN/SI</td>
<td>4.56</td>
<td>1.26</td>
<td>0.55**</td>
<td>0.58**</td>
<td>0.58**</td>
<td>0.32**</td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBC</td>
<td>5.73</td>
<td>1.01</td>
<td>0.36**</td>
<td>0.45**</td>
<td>0.35**</td>
<td>0.77**</td>
<td>0.24**</td>
<td>0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PE</td>
<td>4.85</td>
<td>1.31</td>
<td>0.83**</td>
<td>0.86**</td>
<td>0.96**</td>
<td>0.36**</td>
<td>0.58**</td>
<td>0.34**</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>EE</td>
<td>5.72</td>
<td>1.04</td>
<td>0.38**</td>
<td>0.46**</td>
<td>0.35**</td>
<td>0.86**</td>
<td>0.27**</td>
<td>0.84**</td>
<td>0.33**</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Note: Internal consistency (Cronbach’s alpha) statistics are on the diagonal. *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).


3.2. Variations in BI due to data and participant characteristics

To test the effects of data and participant characteristics on Behavioral Intention, a multiple linear regression analysis was carried out with data-type, system-type, age, gender, and familiarity with ADAS variables. The data-type variable (coded as 0 for simulator data and 1 for online survey data) showed an effect on Behavioral Intention (B = −0.78, SE B = 0.27, β = −0.15, p < 0.05). Hence, acceptance of the systems was significantly higher for participants who experienced the simulated system (mean BI score = 5.31, SD = 1.35) compared to those who read the description (mean BI score = 4.62, SD = 1.60). On the other hand, results could not confirm the effects of system-type, age, gender, and familiarity with ADAS variables. Therefore, the assessment of TAM, TPB, and UTAUT only included the data-type variable in addition to the model factors to control for the differences in the acceptance score due to the different data collection approaches.

3.3. Technology acceptance model (TAM)

3.3.1. TAM (Davis, 1985)

The results showed Attitude and Perceived Usefulness to be significant predictors of Behavioral Intention (Test 1 in Table 4) and Perceived Usefulness and Perceived Ease of Use to be significant predictors of Attitude (Test 3 in Table 4). It was found that the TAM model (Davis, 1985) explained 82% of the variance (Adj. R² = 0.82) in Behavioral Intention. Among the factors of the model, Attitude showed the strongest effect on Behavioral Intention. The results also confirmed the mediating effects proposed in this model (section 1.2). Perceived Usefulness alone can significantly predict Behavioral Intention, with an estimated effect of 1.01 (β, Test 2 in Table 4). However, when Attitude enters the regression model, the effect of Perceived Usefulness reduces to 0.34. This reduction in effect was found to be statistically significant (Z = 14.81, p < 0.05), indicating a partial mediation by Attitude. This also confirms that Perceived Usefulness has a significant effect on Behavioral Intention, above and beyond Attitude. Similarly, it was found that Perceived Usefulness partially mediates the effect of Perceived Ease of Use on Attitude (Test 4 in Table 4). The reduction in estimated effect from 0.62 to 0.25 was statistically significant (Z = 7.68, p < 0.05), confirming the mediation and that Perceived Ease of Use has a significant effect on Attitude, above and beyond Perceived Usefulness. Although, the data-type variable showed an effect on Behavioral Intention (section 3.2), its effect was found to be non-significant in the presence of the model factors (A and PU) (B = −0.12, SE B = 0.11, β = −0.02, p > 0.05).

3.3.2. TAM (Davis, 1989)

Perceived Usefulness and Perceived Ease of Use were found to be significant predictors of Behavioral Intention, and the TAM model (Davis, 1989) was found to explain 73% of the variance (Adj. R² = 0.73) in Behavioral Intention (Test 1 in Table 5). Perceived Usefulness showed a stronger effect on Behavioral Intention compared to the effect of Perceived Ease of Use on Behavioral Intention. Perceived Ease of Use alone can significantly predict Behavioral Intention with an estimated effect of 0.65. However, when Perceived Usefulness enters the regression model, the effect of Perceived Ease of Use reduces to 0.20. This reduction in effect was found to be statistically significant (Z = 7.61, p < 0.05), indicating a partial mediation by Perceived Usefulness. This also confirms that Perceived Ease of Use has a significant effect on Behavioral Intention, above and beyond Perceived Usefulness (Test 2 in Table 5). Similar to the previous analysis, the data-type variable showed no effect on Behavioral Intention in the presence of the model factors (PU and PEoU) (B = −0.04, SE B = 0.14, β = −0.01, p > 0.05).

3.4. Theory of planned behavior (TPB)

The results showed Attitude, Subjective Norms, and Perceived Behavioral Control to be significant predictors of Behavioral Intention, with the model explaining 80% of the variance (Adj. R² = 0.80) in Behavioral Intention (Table 6). Among the factors, Subjective Norms and Perceived Behavioral Control showed very weak effects on Behavioral Intention and Perceived Behavioral Control showed a negative
relationship \( B = -0.08 \) with Behavioral Intention. To further investigate the negative effect of Perceived Behavioral Control on Behavioral Intention with the other model factors, a hierarchical regression analysis (Perceived Behavioral Control entered the model first, then Subjective Norms, and then Attitude) was done. The results showed a positive effect of Perceived Behavioral Control alone on Behavioral Intention \( (B = 0.57, SE_B = 0.07, \beta = 0.36, p < 0.0001) \). When Subjective Norms entered the model, the effect of Perceived Behavioral

### Table 4
Assessment of the Technology Acceptance Model (Davis, 1985).

<table>
<thead>
<tr>
<th>Tests</th>
<th>Adj. ( R^2 )</th>
<th>( B )</th>
<th>SE ( B )</th>
<th>95% CI</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. BI = A + PU</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome: Behavioral Intention</td>
<td></td>
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<tr>
<td>Predictor: Attitude</td>
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</tr>
<tr>
<td>Predictor: Perceived Usefulness</td>
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</tr>
<tr>
<td>2. A mediates the effect of PU on BI</td>
<td>0.72</td>
<td>1.01</td>
<td>0.03</td>
<td>0.95, 1.07</td>
<td>0.85**</td>
</tr>
<tr>
<td>Outcome: Behavioral Intention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor: Perceived Usefulness</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Step 1 Model: BI = PU</td>
<td>0.77</td>
<td>0.85</td>
<td>0.02</td>
<td>0.81, 0.90</td>
<td>0.88**</td>
</tr>
<tr>
<td>Outcome: Attitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor: Perceived Usefulness</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2 Model: A = PU</td>
<td>Same as in Test 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome: Attitude</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Predictor: Perceived Usefulness</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3 Model: BI = A + PU</td>
<td>Same as in Test 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome: Attitude</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Predictor: Perceived Usefulness</td>
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</table>

** ** \( p < 0.0001 \).
Control on BI remained positive (for PBC: $B = 0.37$, $SE = 0.06$, $\beta = 0.24$, $p < 0.0001$); however, when Attitude entered the model, the effect of Perceived Behavioral Control became negative (Table 6). The data-type variable showed no effect on Behavioral Intention in the presence of the model factors (A, SN, and PBC) ($B = -0.15$, $SE = 0.12$, $\beta = -0.03$, $p > 0.05$).

3.5. Unified theory of acceptance and use of technology (UTAUT)

Performance Expectancy, Effort Expectancy, and Social Influence were found to be significant predictors of Behavioral Intention and were able to explain 71% of the variance ($Adj. R^2 = 0.71$) in BI (Table 7). Performance Expectancy was found to be the strongest predictor of Behavioral Intention. Several moderating effects were proposed in UTAUT; however, the results of this study found no evidence of any moderating effect. Similar to the previous theories, the data-type variable showed no effect on Behavioral Intention in the presence of the model factors (PE, EE, and SI) ($B = -0.15$, $SE = 0.04$, $\beta = -0.16$, $p < 0.05$).

3.6. Comparison between TAM, TPB, and UTAUT

The predictive ability of the models assessed was compared using Hotelling’s $t$-test for non-independent correlations. The TAM (Davis, 1985) was found to exhibit the highest adjusted $R^2$ (0.82) among the models and accounted for significantly more variance in Behavioral Intention than did the other three models (Fig. 3). The differences in the ability to predict Behavioral Intention between TPB and TAM (Davis, 1989), TPB and UTAUT, and TAM (Davis, 1989) and UTAUT were also found to be statistically significant. Therefore, TPB performed better than the newer version of TAM (Davis, 1989) and all models performed better than UTAUT in the context of driver acceptance of ADAS.

4. Discussion

This study utilized mixed methods, combining two different data collection approaches, an online survey approach and a driving simulator approach, to study driver acceptance of ADAS. The effects of data characteristics (data-type and system-type) and participant characteristics (age, gender, and familiarity with ADAS) on Behavioral Intention were assessed. Even though this study could not confirm the effects of age, gender, and familiarity, some previous studies have reported significant effects in these factors. Ervin et al. (2005), Li, Li, and Cheng (2015), and Eichelberger and McCartt (2016) investigated the effects of age and gender on acceptance. Ervin et al. (2005) reported a significant effect of age, however could not confirm the effect of gender. Eichelberger and McCartt (2016) did not find any effect of age and gender while Li et al. (2015) reported significant effects of both age and gender. Similarly, Rodel et al. (2014) reported that if the drivers are familiar with an in-vehicle technology, they are more likely to accept them. On the other hand, this study confirmed a significant effect of data-type variable. The results revealed that participants exposed to the driving simulator showed a significantly higher intention to use these systems compared to the participants of the online survey. This difference in acceptance may be attributed to the benefits of a hands-on trial of the ADAS functionalities in the driving simulator. In the simulator, participants had a chance to interact with the system and to understand the role of the ADAS in their driving. The driving scenario simulated routine operational conditions and the participants experienced the ADAS without any driving simulator failures. It is likely that driving simulator participants deemed the simulated system as highly reliable and trustworthy. On the other hand, the online survey participants had to rely on the provided description of the systems to guide their behavioral reaction. Since these types of in-vehicle technologies are not yet prevalent and since most of the participants were not familiar with ADAS functionalities, the described system was not able to motivate the participants as effectively as the driving simulator experience. That is, participants may not have successfully visualized the functionality of the ADAS and their interaction with it. However, previous research indicates that participants themselves believe written descriptions are sufficient. Meschtscherjakov et al. (2009) asked participants whether they could imagine the technology based on the provided description and pictures: 85.7% of the participants said ‘yes’. In a different question, 57.1% of the participants disagreed with the statement that it was difficult for them to respond to the survey items without actually using the technology. These findings, combined with the fact that the majority of the studies in Table 2 which investigated driver acceptance of an ADAS successfully utilized surveys as a tool, provided enough evidence for the suitability of this approach. Furthermore, the results also showed that the different data collection approaches did not lead to a
different pattern of outcomes in the presence of the TAM, TPB, and UTAUT model factors. In the end, although the survey approach did not provide participants the opportunity to interact with an ADAS, both the simulator and the survey approach obtained similar results in measuring the effects of each factor on Behavioral Intention and creating models of driver acceptance of ADAS using TAM, TPB, and UTAUT.

Both versions of the Technology Acceptance Model were found to successfully model Behavioral Intention toward using an ADAS. For TAM (Davis, 1985), Attitude toward using an ADAS was found to be the strongest predictor of Behavioral Intention. This relationship implies that drivers intend to use an in-vehicle technology toward which they have a positive affect or emotion (Davis, Bagozzi, & Warshaw, 1989). Attitude toward a behavior is formed based on beliefs about the outcome of performing the behavior and on personal evaluations of that outcome (Fishbein and Ajzen, 1975). In the context of ADAS, the beliefs that form an attitude may include: the usefulness of the ADAS in enhancing the quality of driving, the effectiveness of the functionality of the ADAS, convenience to the driver, etc. Attitude mediates the effect of these beliefs on Behavioral Intention as it did for the other factor of the model, Perceived Usefulness. Perceived Usefulness, which is defined as a belief, showed a direct effect on Behavioral Intention despite the mediating effect of Attitude. The belief of enhanced performance, in this case, is associated with several rewards: the increased safety of drivers and other road users, reduction in violation of traffic rules, personal satisfaction, etc. This perception of improved performance contributes to the Behavioral Intention to use an ADAS, above and beyond the positive or negative affect associated with that behavior. This study found a larger effect for Attitude on Behavioral Intention compared to Perceived Usefulness. Previous studies have reported both similar (Chen and Chen, 2011) and opposite results (Park and Kim, 2014). A possible explanation of this discrepancy is that these studies did not adopt the TAM model as it was proposed, but rather augmented the model with new factors. In addition, Park and Kim (2014) only analyzed the individual effect of each factor on Behavioral Intention with simple linear regression. The results of the current study also showed that Perceived Usefulness and Perceived Ease of Use can significantly predict Attitude. This result supports the suggestion that Attitude toward a behavior is formed based on relevant beliefs (Fishbein and Ajzen, 1975). Perceived Ease of Use, defined as the belief in the simplicity of a behavior, has two basic mechanisms to affect Attitude: self-efficacy and instrumentality (Davis, Bagozzi, & Warshaw, 1989). If the behavior is easier to perform using the technology, it will create a sense of efficacy and personal control for the performer. Additionally, an easier system would contribute to enhanced performance with the same amount of effort. The enhancement of performance corresponds with the belief of usefulness (Perceived Usefulness); however, with its self-efficacy mechanism, Perceived Ease of Use affects Attitude above and beyond Perceived Usefulness. The same explanation applies to the newer TAM model (Davis, 1989), where a similar relationship between Perceived Usefulness and Perceived Ease of Use was posited and observed in this study. In that model, the mediation of Attitude on how personal beliefs (Perceived Usefulness and Perceived Ease of Use) affect Behavioral Intention was ignored, and Perceived Usefulness and Perceived Ease of Use were considered as predicting variables of Behavioral Intention. The results of the current study found evidence to support the postulates of the newer TAM (Davis, 1989); however, this model was outperformed (based on adj. $R^2$) by the original TAM model (Davis, 1985).

The results of this study found significant effects of the Theory of Planned Behavior (TPB) factors (Attitude, Subjective Norms, and Perceived Behavioral Control) on acceptance (Behavioral Intention). TAM and TPB used the same scale for Attitude, and similar to TAM, in TPB the strongest effect on Behavioral Intention was observed from Attitude. Subjective Norms showed a positive, though very small effect on Behavioral Intention. This result provides evidence that the perception of what other important and influencing people think about performing a behavior influences Behavioral Intention. These influencing people could include family members, colleagues, and even celebrities. It should be noted that the scale of Subjective Norms (as well as the Social Influence scale) did not exhibit acceptable internal consistency. The Subjective Norms scale consisted of two survey items: one measuring the social pressure by influencing people (e.g. idols, celebrities) and the other measuring the social pressure by the people who are important in one’s life (e.g. family members). The lack of internal consistency of the scale indicates that participants considered the two types of social pressure differently. There could be a number of factors that lead people to weigh these pressures differently, such as cultural value, age, etc. Hence researchers should be careful to use this scale and interpret the effect of Subjective Norms (and Social Influence) observed in this study. In contrast, Perceived Behavioral Control exhibited a negative effect on Behavioral Intention in the presence of the Attitude component. Although the effect was very small, this negative effect means that drivers who possess a positive Attitude toward using an ADAS generate a positive behavioral intention to use that ADAS; however, they may expect to have less control over the use of these technologies. This perception of low behavioral control can be attributed to very low familiarity with the technologies used in this study and also to the fact that the survey participants did not get a chance to interact with the described ADAS.

The results of this study also confirmed the predictive ability of UTAUT. The UTAUT factors of Performance Expectancy, Effort Expectancy, and Social Influence exhibited positive effects on Behavioral Intention with Performance Expectancy showing the strongest effect. Based on the definitions (Table 1) of these factors and the scales used in previous studies, it is apparent that Performance Expectancy is very similar to Perceived Usefulness in TAM, Effort Expectancy is very similar to Perceived Ease of Use in TAM, and Social Influence is very similar to Subjective Norms in TPB. The high correlation between these pairs of factors and their comparable effects on Behavioral Intention provides statistical evidence of their similarity. UTAUT was able to explain 71% of the variance in BI, the lowest percentage among the four models. In addition to this empirical evidence, UTAUT includes a total of 8 factors (4 components and 4 moderator variables), which is the highest number of factors among all the models, making the use of this model comparatively demanding. Due to its under-performance, the similarities with TAM and TPB, and the complex nature of the model, UTAUT may not be deemed by researchers to be as useful for modelling driver acceptance of ADAS as other models.

This study has established that the models proposed by TAM, TPB, and UTAUT are able to explain driver acceptance in terms of behavioral intention in the context of ADAS. The question now is, which model performed the best in the current context? The results of Hotelling’s t-test for non-independent correlations showed that the original TAM (Davis, 1985) model is the best performing model, with TPB model as the second best. The TAM model outperformed TPB by only 2% difference in the adjusted $R^2$. The newer TAM (Davis, 1989) and UTAUT had lower performance and were less satisfactory in design. The design of both TAM and TPB is very similar. Both of the models proposed three factors, one of which was shared by both: Attitude. This study used 20 survey items for the TAM (Davis, 1985) model and 18 survey items for the TPB model. With TAM and TPB being so similar in performance and design, researchers should consider the practical significance of adopting one model over the other. TAM provides a mechanism for explaining the formation of Attitude, which was found to be the strongest of the factors in both models, by proposing that Perceived Usefulness and Perceived Ease of Use can predict Attitude. Of the TAM factors, Perceived Ease of Use has the potential to provide actionable information to the developers of in-vehicle technologies. This factor is not considered in TPB. TPB provides information on normative beliefs, behavioral control beliefs and their effects on Behavioral Intention. Practical implications of these factors are less obvious. Considering all these facts, the use of the TAM (Davis, 1985) model to study driver
acceptance could provide more actionable information and explain more variance in Behavioral Intention compared to the other models.

5. Limitations

This study involved two data collection approaches and combined the datasets for analysis; however, the data collection approaches didn’t include the same number of participants. This imbalance in sample sizes may have influenced the effects of the different factors on Behavioral Intention. This is especially a matter of concern when the results showed a significant difference in Behavioral Intention scores due to the different data collection approaches. Secondly, this study required the participants to think about a hypothetical driving route and situation to assess the usefulness of the ADAS in their driving. This is not completely realistic since, during the purchase of such technologies, people would normally think about their own driving needs. Settling on a given driving route allowed participants to find the utility of the ADAS in that situation only, rather than in every possible driving context. In addition, this process made sure that every participant had the same experimental set-up. However, participants’ actual acceptance of those technologies could be different than the acceptance data that was collected in this study. Cruise control may not be useful on torn-up roads, for instance. Thirdly, this study only examined two types of systems whereas there is a large number of systems that fall under the classification of ADAS. More work employing a broader array of ADAS technologies as well as a wider spectrum of traffic and road situations would further enhance our understanding of driver acceptance and the myriad factors that influence it.

6. Conclusions

Advanced Driver Assistance Systems are the future of our transportation system. In March, 2016, the U.S. Department of Transportation’s National Highway Traffic Safety Administration and the Insurance Institute for Highway Safety announced an agreement with 20 automakers representing more than 99 percent of the U.S. auto market to include Automatic Emergency Braking (AEB) as a standard feature on cars no later than Sept 1, 2022 (NHTSA, 2016). This historic event acknowledges the potential benefits of these technologies; federal authorities and vehicle manufacturers will continue to be motivated to develop such technologies. However, the development and inclusion of such technologies are not enough to ensure the usage and thereby gain the potential benefits of these technologies. Even in cases like AEB, where the use of the technology may be mandated, driver acceptance must be ensured or it is possible that the drivers will seek a way around the technology. In these cases, driver acceptance research could be used to discover potential issues and to increase the acceptability of the technology.

Recognizing the importance of driver acceptance research, this study assessed the utility of TAM, TPB, and UTAUT for Advanced Driver Assistance Systems. Two data collection approaches were applied to determine the validity of these theories for modelling driver acceptance and to compare their efficiency. Both approaches yielded similar model analysis results, although ADAS acceptance was higher with the simulator than with the online survey. Each model was able to successfully predict driver acceptance in terms of behavioral intention, and among the models, the original TAM model was found to be the best performing model.

Research efforts should be made to validate the findings of this study across a range of in-vehicle technologies. Researchers have also proposed factors outside of TAM, TPB, and UTAUT that can affect behavioral intention to use an ADAS. Examples of these factors include: Trust (Najm et al., 2006; Ghazizadeh et al., 2012a), Compatibility (Ghazizadeh et al., 2012a), Endorsement (Najm et al., 2006; Stearns and Vega, 2011; Nodine et al., 2011), Affordability (Regan et al., 2006), and Reliability (Källhammer et al., 2007; LeBlanc et al., 2008; Van Houten et al., 2014). Future studies should investigate the predictive abilities of these factors and how these factors can be utilized to augment the theoretical acceptance models.

Acknowledgments

Data collection for the driving simulator study was done at the Liberty Mutual Research Institute for Safety (LMRIS). The authors would like to especially acknowledge Lucinda Simmons, Angela Garabet, and Sarah Hong of LMRIS for their support in the driving simulator study. The primary author was supported, during his work at LMRIS, by a Liberty Mutual Safety Research Fellowship. The primary author wishes to thank the American Society of Safety Engineers and the Liberty Mutual Research Institute for Safety who jointly sponsored this fellowship.

Appendix A. Scales used to measure the factors of TAM, TPB, and UTAUT

Technology Acceptance Model (TAM)

Attitude (adapted from Van der Laan, Heino, & De Waard (1997))

1. The use of the system when I am driving would be: Bad : 1: 2: 3: 4: 5: 6: 7: Good
2. The use of the system when I am driving would be: Useless : 1: 2: 3: 4: 5: 6: 7: Useful
3. The use of the system when I am driving would be (reverse-scaled item):
5. The use of the system when I am driving would be: Sleep-inducing: 1: 2: 3: 4: 5: 6: 7: Alerting
7. The use of the system when I am driving would be: Extremely Annoying : 1: 2: 3: 4: 5: 6: 7: Not at all Annoying
8. The use of the system when I am driving would be:
9. The use of the system when I am driving would be (reverse-scaled item):

Perceived Usefulness (adapted from Venkatesh and Davis (2000))

10. Using the system would improve my driving performance.
11. Using the system in driving increases my safety.
12. Using the system enhances effectiveness in my driving.
13. I would find the system useful in my driving.

Perceived Ease of Use (adapted from Venkatesh and Davis (2000))

14. My interaction with the system would be clear and understandable.
15. I would find the system difficult to use (reverse-scaled item).
16. Interacting with the system would not require a lot of mental effort.
17. I would find it easy to get the system to do what I want it to do.

Theory of Planned Behavior (TPB)

Attitude: Same as TAM
Subjective Norms (adapted from Venkatesh and Davis (2000)). [18] People who influence my behavior would think that I should use the system.
19. People who are important to me would not think that I should use the system.
Perceived Behavioral Control (adapted from Venkatesh et al. (2003))

[20] I have control over using the system.
[21] I have the resources necessary to use the system.
[22] I do not have the knowledge necessary to use the system (reverse-scaled item).
[23] Given the resources, opportunities and knowledge it takes to use the system, it would be easy for me to use the system.

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Performance Expectancy (adapted from Venkatesh et al. (2003) and Adell et al. (2010))

[24] I would find the system useful in my driving
[25] Using the system would enable me to react to unsafe driving conditions more quickly
[26] Using the system would improve my driving performance
[27] If I use the system, I will decrease my risk of being involved in an accident

Effort Expectancy (adapted from Venkatesh et al. (2003) and Adell et al. (2010))

[28] My interaction with the system would be clear and understandable
[29] It would be easy for me to become skillful at using the system
[30] I would find the system difficult to use
[31] Learning to operate the system would be easy for me

Social Influence: Same as the Subjective Norms scale in TPBFamiliarity (author created scale). [32] You have just experienced an intelligent driving system. Prior to this experience, please indicate your familiarity with such systems:
- o I have never heard of a similar driving system (familiarity level 1).
- o I may have heard of a similar driving system (2).
- o I am moderately familiar with similar systems but never used when driving (3).
- o I am quite familiar with similar systems but never used when driving (4).
- o I’ve had few instances when I used similar systems when driving (5).
- o I occasionally use a similar system when driving (6).
- o I regularly use a similar system when driving (7).

Behavioral Intention (adapted from Adell (2010))

[33] If the system is available in the market at an affordable price, I intend to purchase the system.
[34] If my car is equipped with a similar system, I predict that I would use the system when driving.
[35] Assuming that the system is available, I intend to use the system regularly when I am driving.

Note. All items (except for the questions that has scales given) was averaged on a 7-point Likert scale, where 1 = strongly disagree, 2 = moderately disagree, 3 = somewhat disagree, 4 = neutral (neither disagree nor agree), 5 = somewhat agree, 6 = moderately agree, and 7 = strongly agree. To measure the factors, participants’ ratings on the survey items under each scale was averaged.

Appendix B. Description of the driver assistance systems and driving scenarios

System 1

You have recently bought a new car and among its features is a driver assistance system that is designed for safe driving. The system can be turned on using a button on the steering wheel. The system can be turned off at any time by pressing the same button on the wheel or by pressing on the brake pedal. Once the system is turned on, it will:
- Keep your car in the lane it is currently travelling in
- Keep the car at a constant speed, slowing down around curves as necessary
- Keep a safe distance from other vehicles and obstacles around you
- Stop at a safe distance from stopped vehicles and obstacles and at intersections with red lights.

The driver assistance system cannot automatically change lanes. If you need to change lane, you will need to disengage the system. If the system stops the vehicle at an intersection, it can automatically start moving the vehicle once the traffic light is turned green and eventually it will drive the vehicle at the set speed, if the traffic conditions allow.

Now, suppose that you need to commute to work that takes about 30 min on each way. Commuting to work could sometimes be frustrating, however, you are used to it. You live in a suburban area outside a large city, where you work. Your commute includes driving through the residential area in your town, then driving about 20 miles on an interstate followed by driving through the city center. The traffic is generally sparse until you enter the city. Driving in the city involves several signalized intersections, therefore frequent stop-and-go traffic. You are thinking about whether you should use the driver assistance system described above while commuting to work.

System 2

You have recently bought a new car and your car is designed with a feature that can monitor driver alertness based on driving behavior. The system uses a front camera to detect the lane position of the vehicle and based on the information gathered, it evaluates driver alertness. If the system detects a drop in driver alertness, it gives a soft audible and visual warning. If driver alertness further drops, it will give a hard warning with a chime that must be acknowledge by pressing a button on the steering wheel. If the vehicle is stopped and the driver’s door is opened, the system will reset itself. The system can be turned off at any time using settings in the instrument cluster.

Now, suppose that you need to commute to work that takes about 30 min on each way. Commuting to work could sometimes be frustrating, however, you are used to it. You live in a suburban area outside a large city, where you work. Your commute includes driving through the residential area in your town, then driving about 20 miles on an interstate followed by driving through the city center. The traffic is generally sparse until you enter the city. Driving in the city involves several signalized intersections, therefore frequent stop-and-go traffic. You are thinking about whether you should use the driver assistance system described above while commuting to work.

References
