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Can Drivers Construct Accurate Understanding of Tesla's Autopilot?

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ABSTRACT

Background: Equipped vehicles with advanced driver-assistance systems (ADAS) are quickly becoming ubiquitous. Examples of ADAS include forward collision warning (FCW), automatic emergency brakes (AEB), lane departure warning (LDW), lane keeping assistance (LKA), adaptive cruise control (ACC), and blind spot warning (BSW) (Pradhan et al., 2022b). The goal of these systems is to safeguard drivers by giving warnings, like BSW, or by automatically controlling vehicle speed and direction in specific circumstances, like LDW and ACC (Pradhan et al., 2022). By 2025 most passenger vehicles will be equipped with some ADAS features (Krisher, 2024). Tesla unveiled its Level 2 automated driving feature called Autopilot, which brings together ACC, LKA, and autosteering to enhance driving automation (Chen & Terken, 2023). The promise of these technologies is to increase convenience and traffic safety if they are used appropriately. However, average drivers may not be able to develop appropriate level of trust because of the inability to explain the system. By studying the drivers understanding of automation and its limitation, one can gain a better understanding of drivers' limited knowledge of the system, which can lead to an initial high level of trust in the system and complacency (Beggiato & Krems, 2013). This qualitative study examines drivers' understanding of Tesla Autopilot after driving an equipped vehicle for a working week.
Methods: Ten participants were recruited and drove a Tesla Model S during a working week for daily freeway commutes. Participants were interviewed about ADAS actions by using situational questions. Semi-structured interviews allowed for more probing of participants' early mental models. All interviews were audio-recorded, transcribed, and examined using thematic analyses.
Results: Based on the literature about human-machine teaming, three major concerns related to trust in automation, Misuse, Disuse, and Abuse of automation are used as codes for analyzing transcripts of interviews. Although the overall majority of participants' early mental models were consistent with the systems, there are areas of concern related to understanding regarding Tesla's Autopilot limitations, specifically in city driving.
Conclusion: The findings of this study indicate that there is a need for training drivers on level 2 autonomous driving systems such as Tesla's Autopilot to ensure safe use of advanced technologies.

Keywords: Autonomous driving, Human automation interactions, Trust in automation, Mental models, Partial automation

INTRODUCTION

Advanced Driver Assistance System (ADAS) includes all safety features in cars that utilize cameras and sensors to provide safety alerts or assist drivers with braking or steering to enhance the safety of driving (Chen & Terken, 2023). The four general performance categories of ADAS are braking, steering, warning, and monitoring (Staples et al., 2024). ADAS includes Automatic Emergency Braking (AEB) that automatically stops the vehicle if it is in danger of striking the vehicle in front of it, adaptive cruise control (ACC) systems assist with acceleration and braking to maintain a specified distance between the vehicle and the vehicle ahead, lane keep assist (LKA), lane centering (LC), lane departure warning (LDW), forward collision warning (FCW), and blind spot warning (BSW) (Staples et al., 2024). New developments in ADAS have made the technologies available to a wide passenger vehicles (Chander Dhawan, 2019). A report published by the American Automobile Association (AAA) concluded that 92.7 percent of new cars available in the U.S. market as of May 2018 are equipped with at least one ADAS feature (American Automobile Association, 2019). ADAS has demonstrated its value in saving lives, preventing injuries, and reducing traffic congestion (Pradhan et al., 2022; IIHS, 2010; Jermakian, 2011). To increase the degree of driving autonomy and safety even further, automakers have been combining ACC with other ADAS features like LKA. Tesla refers to this feature as Autopilot. The Autopilot allows drivers to leave the driving to the vehicle while still being vigilent and actively monitoring their vehicles (Chen & Terken, 2023). The Society of Automotive Engineers (SAE) categorizes Tesla's Autopilot as level 2 or partial automation, which means the car can control steering, acceleration, and deceleration, but the driver still needs to be attentive at all times and remain in the drivers' seat to take over control anytime needed (Teoh, 2020).

Drivers must understand the limitations of the system to avoid using it beyond its design conditions and limitations due to the fact that the Autopilot still has limitations and vehicles cannot operate entirely autonomously. But potential drivers may think such systems are more capable than they really are. According to AAA's survey, almost 40 percent of drivers think that a partially automated driving system, such as ProPilot Assist or Autopilot, can drive vehicles itself unconditionally (American Automobile Association, 2019). A similar finding is reported by the Insurance Institute for Highway Safety (IIHS), where 48 percent of drivers claimed that it is safe to get distracted by gadgets such as mobile phones while using a partially automated driving system (The Insurance Institute for Highway Safety, 2019). The gap in drivers' awareness of advanced technologies is not limited to new systems (McDonald et al., 2016). In a comprehensive study performed at the University of Iowa, subjects demonstrated their lack in knowledge of well marketed and standard technologies such as Anti-lock Braking System (ABS) and tire pressure monitoring systems (McDonald et al., 2016).

Trust is a factor that increases the likelihood of acceptance with Adavanced technologies such Tasla's Autopilot (Choi & Ji, 2015). With automation in general the lack of knowledge not only can cause inappropriate and unsafe use of advanced systems, but also can displace drivers' trust and cause inappropriate and unsafe use (misuse) of advanced systems (Lee & See, 2004; Parasuraman & Riley, 1997). To prevent unsafe scenarios, humans must adjust their expectations based on the reliability, capabilities, and trustworthiness of systems, like Tesla's Autopilot, because partial automation requires human active monitoring and intervention (Lee & See, 2004). Users must adjust their trust in automation to match the reliability of the system for successful collaboration between humans and systems (Mouloua & Mouloua, 2018; Parasuraman & Miller, 2004). To achieve this, users must develop more accurate mental models of systems to predict their actions (Deutsch, 1958; Lee & See, 2004; Merat & Madigan, 2016; Muir, 1987). Various sources such as experience, interaction with others, and education are used to form a dynamic representations in our head that directs our actions and are called mental models (Helander, 2014; Johnson-Laird, 1994). As argued by Parasuraman and Riley (1997), imprecise mental models of a system brings about misuse, disuse, and abuse of technology. Misuse refers to failures that occur due to over-reliance on automation (Parasuraman & Riley, 1997). Disuse refers to the failures that occur when humans rejects the help of automation when it could have been useful (Parasuraman & Riley, 1997b). Abuse refers to incorrect deployment of automation by the designers without considering the consequences - for example, using automation where human input is critical.

Engaging in secondary tasks while using automation despite being required to monitor the systems is an indication of excessive trust in the systems and complacency among drivers (Merat & Lee, 2012, Schwarz et al., 2023). Complacent drivers fail to monitor which can lead to inadequate situation awareness in critical traffic scenarios (Soli's Marcos et al., 2018). Complacency has been observed in higher levels of automated driving when tracking drivers' visual attention while driving automated vehicles, which is concerning (Carsten et al., 2012; Louw & Merat, 2017). Additionally, the narration of several recent crashes such as the Tesla model S incident in Utah, where the driver failed to react to the stopped fire engine ahead while the vehicle was in automated (Autopilot) mode, shows that concern is justified (Brandy McCombs, 2018). Drivers may not anticipate vehicle behavior and not react to road hazards when intervention is needed due to a lack of understanding of vehicle automated systems and their limitations (Parasuraman et al., 2008; Victor et al., 2018). To address the stated concern, scholars such as Stanton (2018) have highlighted the importance of training drivers on the advanced driver-assistance technologies (Kyriakidis et al., 2017). Understanding the early mental models of drivers can help us identify common misunderstandings and design training (Noyes et al., 1996; Hancock et al., 2009; Plant & Stanton, 2017; Healthcare & Karwowski, 2006; Jonassen, 1995; Neisser, 1987). For extracting mental models, verbal methods such as semi-structured interviews have proven their eliciting power in critical scenarios (Plant & Stanton, 2017; Revell & Stanton, 2010; Sanderson et al., 1989).

In our naturalistic driving study, semi-structured interviews were used to uncover drivers' understanding of Tesla Autopilot after driving with a partially-automated Tesla model S for a week (Monday to Friday). The hypothesis is that drivers can construct a correct mental model of Tesla's Autopilot and its limitations without receiving training.

METHOD

A Tesla Model S 75D, equipped with the enhanced Autopilot version 2, was used as the test vehicle for driving on Interstate road in a naturalistic setting (Gaspar and Carney 2019). It is worthwhile to mention that the enhanced Autopilot is a group of advanced driver-assistance systems, including: Traffic Aware Cruise Control (TACC), Autosteer, Collision Warning, Automatic Emergency Brake, and Auto Lane Change (Model S Owner's Manual, 2019; Williston, 2017). The Autopilot system employs multiple cameras, a radar linked to TACC, and ultrasonic sensors to enable the vehicles to self-steer, adjust speed, and apply brakes to reduce human errors and traffic accidents (Anderson et al., 2016).

Email invitations were sent to eligible participants to participate in the study through the Driving Safety Research Institute subject registry, which was previously called the National Advanced Driving Simulator (NADS) subject registry. To be considered, drivers must have Adaptive Corus Control (ACC) equipped vehicles and not have any prior experience with Tesla's Autopilot. This consideration was implemented to speed up driver learning of the ADAS technology used in the study vehicle due to the limited time available for interaction with the vehicle in this study. A total of ten drivers living in Cedar Rapids, Iowa and working in Iowa City during the week were qualified and participated in the study. After meeting the requirements, the participants provided written informed consent. All study procedures were approved by the University of Iowa IRB. During weekends, they were taught about Tesla and its systems in two sessions to make sure they can safely operate the car and its systems. In the first session, participants learned how to use climate control, wipers, radio, autosteering, Adaptive Cruise Control (ACC), and lane change while using ACC. In the second training session, the focus was on practicing what participants learned in the first session by driving the car on the highway and using the automated features. After each session, participants were asked to drive the vehicle to demonstrate their ability to activate and use the technologies during the study.

A checklist was utilized to assess participants knowledge. After completing training sessions successfully, participants drove research vehicles for working weeks. (i.e., Monday to Friday) from their homes in the Cedar Rapids, region, Iowa, region to the Driving Safety Institute and parked the vehicle at the location in the mornings. Participants returned in the afternoons each day to collect the research vehicle and commute to their homes. The vehicle was kept until the next morning. Drivers were given instructions to utilize the Tesla Autopilot solely on the divided highway between Iowa City and Cedar Rapids. Each participant returned the vehicle on the next Saturday after completing a week of study. After returning the vehicle for the final time, they took part in a semi-structured interview for measuring their mental models (Novak & Gowin, 1984; Smith et al., 1996).

"What does the car do if" "questions were asked to gain insight to participants' mental models of Tesla's advanced technologies. These questions investigated how Autopilot function in the scenarios listed in the Table 1. Follow-up probing questions were asked as necessary such as "Why do you think so?" or "Where did you learn this?" (Stanton, 2013). Scenarios were developed based on frequent discussion topics on driving forums, news, and crashes involving Tesla in two sections pertaining to city driving and highway driving (Fred Lambert, 2016; James Langford, 2018; Muoio, 2016; Tesla Forum, 2016). It is important to note that questions assessed the general understanding of participants in those scenarios. The training did not cover the scenarios, and the participants did not encounter most of them while driving. This study focus is on analyzing developed mental models and inferences based on a week of driving the vehicle. All interviews have been audio recorded and transcribed for the subsequent analysis. The study was approved by the Institutional Review Board (IRB) at the University of Iowa (IRB number: 201707753).

Table 1: Scenarios for "What if" questions.

Systems	Scenarios
Autopilot	Ice covered road Curves in the road Approaching a cyclist and motorcycle Changing lanes automatically Driving on Autopilot in City A stopped vehicle on the road ahead of your car A road construction a head of your car An emergency vehicle getting close to the car
ADAS for city driving such as Automatic Emergency Braking (AEB)	Approaching a roundabout A pedestrian who suddenly jumps in front of the car Intersection Traffic light

Analysis

The interviews have been completed by 9 out of 10 participants. One participant declined after completing the driving sessions and has decided not to take part in the interview. A deductive analysis approach (Crabtree & Miller, 1992) was used to identify pitfalls in drivers' general mental models of the vehicle, which can result in uncalibrated trust. Based on Parasuraman and Riley (1997), two codes are used for data analysis: misuse, disuse, and abuse of automation.

An independent coder, analyzed and coded transcription independently. The intercoder reliability of the analysis was tested by an independent coder. The second coder was familiar in the field of human factors, but did not have case specific knowledge nor was involved in the research. Inter-rater agreement between coders using Cohen's kappa coefficient 0.85 which gives the confidence in the coding scheme (Lazar et al., 2017).

Results

The interview analysis revealed that although participants had a good grasp of Tesla Autopilot's capabilities, there were several instances of inaccuracy that could lead to misuse and disuse. Misusing the Autopilot is a result of misunderstanding its limitations, and disusing it is a result of misunderstanding the system's purpose. Automation's misuse and disuse are discussed in the following sections, and the number of participants who discussed a similar theme is also given in parentheses. The numbers are given for illustrative purposes only, and should not be used for statistical inference due to the small sample size and non-representative sample.

Misuse of Automation (Misunderstanding ADAS Limitations)

The Tesla's autopilot is intended for driving on dry, straight roads with clear road markings, such as highways, while an attentive driver supervises the system (Tesla Motors Inc., 2016). The user manual provided to participants contains information on limitations of use, and it is recommendefor their insightful and constructived that participants review it. Although most participants have developed accurate mental models of the limitations, a few participants made statements that fall under the theme of misuse of automation during the interview. This refers to the use of the autopilot in situations that are not appropriate. Excerpts from interviews are used to demonstrate these statements.

ADAS should not be utilized on roads with ice, as stated by most of the participants (n = 8 out of 9). Their primary reasoning was that the road surface marking will not be accessible. One participant made an incorrect statement that the car likely has an advanced system that can detect ice and turn off the autosteer system.

Only two participants (n = 2 out of 9) correctly stated that none of the advanced car technologies can react to situations like roundabouts, intersections, and red lights in their answers. Two participants stated that they do not know what the car would do in each of the mentioned scenarios. A participant mentioned that the car can navigate roundabouts and stop at red lights, but does not respond to intersections because there are no markings to follow. The others (n = 4 out of 9) have stated that Tesla's Autopilot can circle roundabouts, stop at red lights when the lights are red, and react at intersections. One participant erroneously stated that a car's autopilot can be utilized for city driving.

Disuse of Autopilot

During the open-ended questions, a participant stated that the objective of Autopilot is to correct driver errors. Tesla autopilot is considered level 2 of automation and human drivers are still responsible for monitoring and controlling the system in complicated situations(Gordon & Lidberg, 2015). A participant's statement indicates that they had a misconception of the purpose of ADAS and the driver's role in the system. This misunderstanding can potentially lead to the disuse of the technologies.

"At the end of the day we know drivers should drive the car and all these advanced technologies are installed there to correct them."

DISCUSSION

The objective of this study was to analyze whether drivers can construct accurate mental models of the Autopilot without receiving training. Drivers who lack experience and accurate knowledge may engage in dangerous behavior and complacency, which is why examining early understanding and mental models are crucial (Underwood, 2005). In our analysis, we identified misunderstandings that could lead to misuse or disuse of the Autopilot. Some responses to the inquiries display misunderstanding of the system's functions and purposes.

Other studies that examined the early exposure of drivers to ADAS have revealed a rise in complacency and the probability of engaging in secondary tasks, particularly over time (Merat et al., 2012; Ruscio et al., 2015). The optimal solution is to adapt higher levels of automation where drivers will no longer have to monitor (Stanton, 2018). In the meantime, it is necessary to train drivers on partial automated driving capabilities, keeping in mind that the tasks that drivers have in manual and automated driving differ.

In this study we observed one statement which demonstrated a confusion about the Autopilot purpose. Drivers may mistakenly believe they are still in automated mode even when the system has switched to fully manual driving due to driver inputs disengaging the Autopilot (Wilson et al., 2020). This could lead to potential mishaps (Cooling & Herbers, 1983; Durbin, 2017). While trainings can address this confusion, aviation mishaps like Aeroflot Flight 593 show the significance of visible and multimodal feedback when automated systems deactivate (Center & Holden, 2013; Cookson, 2017). In the report of the National Highway Traffic Safety Administration (NHTSA), there is a concern about status feedback regarding automation mode and it needs more investigation (Campbell et al., 2018).

This study was constrained by multiple limitations. All participants had TACC-equipped vehicles. This prevented us from exploring the mental models of drivers unfamiliar with TACC technologies. The findings could be influenced by the backgrounds and exposure of participants to various systems. Furthermore, we did not conduct pre-driving surveys to examine how driver knowledge of Tesla's autopilot changed or shaped during a one-week drive of the vehicle. Another limitation is that the context of the study and pre-training may have influenced participants to pay closer attention to systems and their functionalities, leading them to have better understandings of the systems than other drivers. In our study we had a small sample size and only 9 participants agreed to complete the interview, thus Future research should use a larger sample size of subjects from different age groups, experience levels, and education levels to evaluate drivers' mental models before and after interacting with the Autopilot. It is important to note that while some statements suggest misuse and disuse of the system, there is no direct correlation between questionnaire responses and behavior.

CONCLUSION

Although drivers showed a good understanding of the Tesla Autopilot, there were some instances where lack of knowledge was observed, which, along with inappropriate usage, can lead to unsafe conditions. Therefore, in order to increase driver awareness of autonomous driving and road safety, initial training can play a crucial role. Due to the limited number of participants, it would be advantageous to study drivers' comprehension of autonomous driving features and their mental models in a wider range of individuals with different backgrounds.

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