How Does Training Influence Use and Understanding of Advanced Vehicle Technologies: A Simulator Evaluation of Driver Behaviour & Mental Models

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Abstract

Advanced vehicle technologies such as Advanced Driver Assistance Systems (ADAS) promise increased safety and convenience but are also sophisticated and complex. Their presence in vehicles affect how drivers interact with the technologies, and how much drivers must know about these technologies. To maximize safety benefits drivers must use such systems appropriately. They must not only understand how these technologies work, but also how they may change drivers' traditional responsibilities. Training has been an effective tool for accelerating knowledge and skills in traditional driving. Consequently, training is gaining recognition as an important tool for improving drivers' knowledge, understanding, and appropriate use of vehicle technologies. This study evaluated the effects of different training methods on drivers' use and understanding of vehicle automation. Licensed drivers with little to no experience with vehicle ADAS systems were randomly assigned into groups based on three training conditions: two experimental groups, 'User Manual' and 'Visualization,' and a control group with a 'Sham' training. Participants were surveyed on their understanding of an ADAS technology (Adaptive Cruise Control – ACC) before and after training. They also drove an advanced driving simulator equipped with ACC. The simulated drive offered multiple opportunities for the drivers to interact with the ACC and included embedded cues for engaging with the system and embedded probes to measure driver awareness of system state. The results found a significant overall increase in knowledge of ACC after training for the experimental groups. Drivers in the experimental training groups also had better real-time awareness of system state than the control group. The results indicate that training is associated with improved knowledge about the systems. It also shows differential effects of different approaches to training, with text-based training showing greater improvement. These findings have important implications for the design and deployment of these systems.

Keywords: Vehicle Automation; Mental Models; Driver Training; Driving Simulation; ADAS; ACC;

1. Introduction

Advanced vehicle technologies such as Advanced Driver Assistance Systems (ADAS) promise increased safety and convenience. These systems are being offered in most modern vehicles and thus are increasingly easily available, accessible, and achieving ubiquity [1]. However, these systems are inherently sophisticated and complex, and their presence in vehicles affect (a) how drivers interact with the technologies, and consequently (b) how much drivers must know about these technologies. These two are closely related. For the former, because the systems assist with vehicle control, a driver's role as an engaged operator change. Relegation of the control tasks to automation decreases drivers' control responsibilities and increases monitoring responsibilities [2]. For the latter, drivers' knowledge of system capabilities and limitations affect how appropriately they use the system. To maximize safety benefits drivers must use the systems appropriately and correctly, and therefore must understand how these technologies work, and how they may change drivers' traditional responsibilities. This understanding of these systems can be thought of as drivers' mental models. Mental models can be defined as "A rich and elaborate structure which reflects the user's understanding about the system's contents, its functionality and the concept and logic behind the functionality" [3].

Drivers' mental models can be influenced by design, interfaces, feedback, awareness, and training [4]. While intuitive and careful design of these systems can help with drivers' learning and understanding, the systems are complex enough that elegant design alone may not suffice, and training may be a necessary component of ADAS use. Training has rich history in improving driver safety and performance in traditional driving. Training has been shown effective in accelerating higher-order skills and knowledge in traditional driving [5]. Similarly, training has an important role, and is gaining recognition as a potentially critical tool for improving drivers' knowledge, understanding, and appropriate use of vehicle technologies [6].

In this study, we studied the effects of different training methods on drivers' use and understanding of vehicle technologies, namely Adaptive Cruise Control (ACC). We evaluated training approaches using a driving simulation platform. In this study, we operationalized the term 'driver use' as actual driver operation of systems in a simulated environment, and 'understanding' as assessed by measuring drivers' mental models of the system. The rest of this document details the methods and the findings of this evaluation.

2. Methodology

2.1. Participants

Twenty-four participants were recruited to participate in the study, evenly divided by sex. The average participant age was 24.8 years (SD = 8.57 years). Participants were pre-screened for age, licensure, and understanding of ACC functionalities and limitations. Those who had valid licenses, had at least three months of driving experience and were between the ages of 18 - 65 were eligible for the study. An important inclusion criterion was that all drivers were self-reported novice users of ADAS, i.e., with little or no knowledge of ACC.

2.2. Experimental Design

A mixed, between and within group experimental design was used for this study, with time (pre-test & post-test) as the within subject factor and Training Method as the between subject independent variable. The three levels of the Training Method independent variable included two experimental groups ('User Manual' and 'Visualization',) and a control group ('Sham' training).

The dependent variables included:

(1) Drivers' knowledge of ADAS as measured by a mental model survey (Completeness and Accuracy of Mental Models Survey – CAMMS [7]). The survey evaluated drivers' knowledge of ACC, its functionality, capabilities, and limitations. This survey was administered before training to establish a baseline knowledge of ACC, and then again after training. The survey consists of 75 unique items and all participants answered on a scale of 1 (Strongly Disagree) to 6 (Strongly Agree). Participants' scaled agreement responses were then translated on a scale of 0 to 100 and an overall Mental Models score was derived from the average of all questions for each participant.

(2) Accuracy of drivers' real-time verbal responses to probes about ADAS status. At various times during the drive, participants received a pre-recorded verbal probe asking questions about the state of the ACC. Participants were expected to verbally respond to these probes. Examples of these verbal probes include "What Speed are you currently travelling at?" or "What is the current ACC Distance Setting?", or "Is ACC currently active?". There were six verbal probes over the duration of the drive.

(3) Accuracy of drivers' real-time manual responses to instructions to operate the ADAS during the drive. During the drive, participants were instructed via a pre-recorded verbal message, to perform certain operations with the ACC. The operations included actions such as changing ACC speeds or distance settings

(4) Reaction time for drivers' manual responses.

2.3. Driving Simulator & simulated routes

A high fidelity fixed-base full-cab driving simulator running the Realtime Technologies (RTI) SimCreator engine was used for this study. The RTI fixed-based driving simulator consists of a fully equipped 2013 Ford Fusion cab placed in front of five screens with 330-degree field of view. The cab also features two dynamic side-mirrors and a rear-view mirror which provide rear views of the scenarios for the participants. The simulator is equipped with a five-speaker surround system for exterior noise and a two-speaker system for simulating in-vehicle noise (Figure 1). RTI's SimADAS equips the simulator with ADAS features such as Adaptive Cruise Control, Traffic Jam Assist, etc. The ACC system mimics those in the real world and can maintain the vehicle's speed and distance from lead vehicle according to the operators' set parameters. The SimCreator engine also makes it possible to script various traffic and edge case events and introduce alerts and visual notifications to the drivers through the instrument panel and center console of the cab. In addition to vehicle measures, the simulator also collects real-time video recordings of the participants hand movements, feet movements, and verbal responses.

Figure 1. Fixed-Base Driving Simulator

All participants drove for approximately ten minutes in the simulator. Two separate drives were designed for this experiment with a reversed sequence of driving scenarios for counterbalancing purposes. Each participant drove one of the two drives. The drives consisted of both urban and rural roadways with other traffic and road users, and commonplace driving events and scenarios. Speed limits were 65 mph on urban roads and 55 mph on rural roads.

2.4. Training approaches

Three training approaches were designed for this study: Visualization (V), Text Based User Manual (M), and Sham (S).

The Visualization Training was based on prior conceptual work [8] on advanced vehicle technologies. Accordingly, the training content included a visual representation of an ACC system as a state diagram (See Figure 2 for an example of the illustration). The diagram displayed the various possible states (or conditions) that an ACC could attain within circles. The connectors between the states explained how one could switch between conditions by using various controls. For example, a circle could represent an "Acc ON" state, and another circle could represent an "Acc OFF" state and connecting lines between the circles showed that one could move from one state to the other using various controls (e.g., the ON button on the steering wheel). The visualization was further supplemented with some instructions about limitations of ACC.

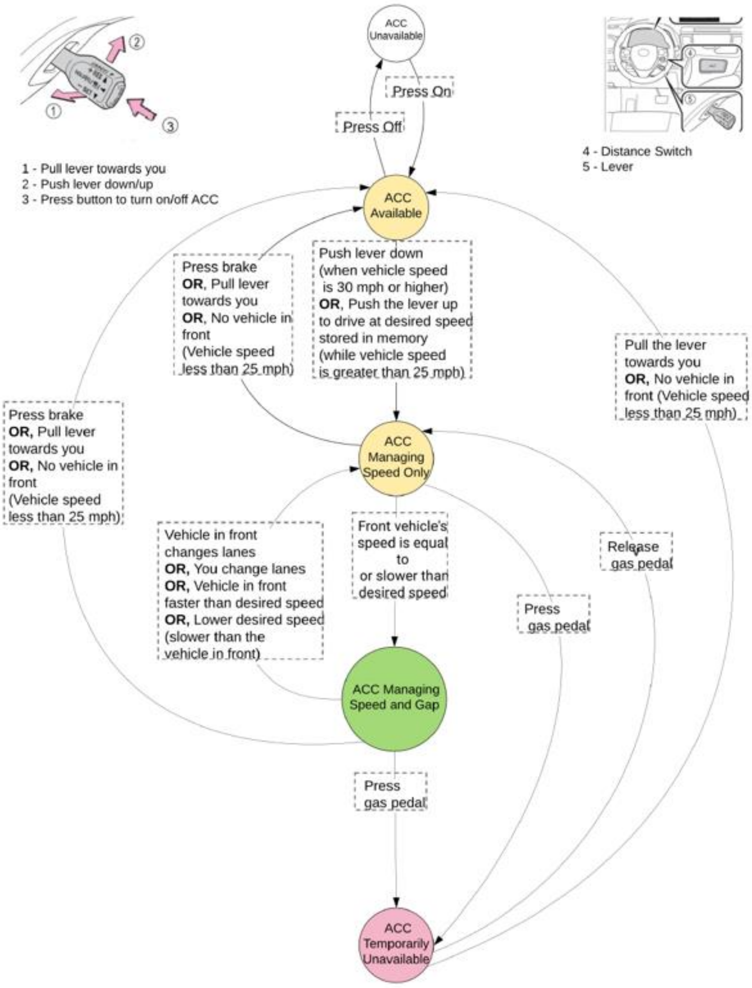

Figure 2. Visualization Training State Diagram

The Text Based User Manual training included written descriptions and warnings about ACC generally found in an owner's manual. For this study, the content for this approach was compiled from actual user manuals of vehicles that offered ACC but presented in a simplified format to minimize time spent searching for relevant information. This method contained no visualizations other than schematic diagrams of control buttons.

The sham training was included in the design as a control. This training approach consisted of text description of unrelated ADAS features, i.e., Forward Collision Warning systems (FCW) and Lane Departure Warning Systems (LDW) that were derived from user manuals and presented in a manner like the Text Based User Manual training.

2.5. Experimental Procedure

The experimental study protocol was approved by the Institutional Review Board. The study required participants to undertake a visit to the driving simulator laboratory. All participants completed an informed consent form. Participants then completed a demographics survey, a Trust survey [9], and the CAMMS survey [7]. The participant was then administered the training intervention based on the condition that they had been previously randomly assigned to. Following training, participants were again administered the trust and CAMMS surveys.

After completion of all surveys, participants completed the simulator drives. Participants were familiarized with the driving simulator platform and the ACC system in the simulator with verbal instructions followed by a brief familiarization drive. Once participants stated they were comfortable, they started the experimental drive. They drove an advanced driving simulator equipped with ACC. The simulated drive offered multiple opportunities for the drivers to interact with the ACC and included embedded cues for engaging with the system and embedded probes to measure driver awareness of system state. Drivers' operation of the system controls and drivers' verbal responses to embedded probes were recorded.

3. Analysis and Results

Drivers' use and understanding of ACC were measured and analyzed across the following outcomes: Knowledge of ACC, awareness of system state in real-time, and accuracy and speed of driver actions while engaging in ACC state changes.

3.1. Drivers understanding of ACC

Figure 3 illustrates the average mental model scores (CAMMS scores) for all participants and by group. A two-way 3 (type of training method: M, S or V) x 2 (Condition Type: Pre or Post Training Scores) mixed analysis of variance with repeated measures on the survey score variable was conducted. The analysis found a significant effect of condition type, but no main effect of training method. The main effect of condition type yielded an F ratio of $F(1,21) = 30.951$, $p<0.001$, with a significant difference between Pre-Training Survey ($M = 54.255$, $SD = 10.32$) and Post Training Survey ($M = 65.455$, $SD = 11.83$). This suggests that participants' knowledge changed between Pre and Post Training Surveys, while the training type (M, S or V) had no effect on the participants' knowledge.
The pairwise comparisons for the main effect of condition type were corrected using a Bonferroni adjustment method. The test indicates a statistically significant effect between Pre-Training and Post Training Survey, specifically for Visualization Group ($p = 0.01$) and Text-Based group ($p = 0.04$), but not for the Sham group.

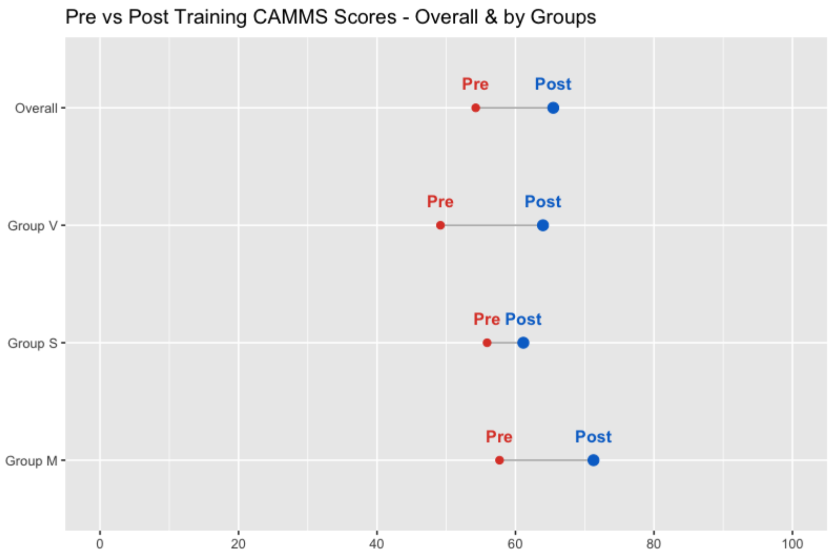

Figure 3. Driver knowledge before and after training

3.2. Accuracy of Verbal responses

Figure 4 represents the average accuracy of the drivers' verbal responses to the probes about ACC as they drove. The participants who received manual training and visualization training had higher mean accuracy of verbal responses (0.85 and 0.77, respectively) than the control group (0.708). A one-way ANOVA was conducted to analyze the accuracy of verbal responses based on the participants' training group. Analysis revealed that there was no main effect of training group on the accuracy of participants' verbal responses ($F = 1.4863$; $p = 0.229$; $\eta^2 = 0.02$).

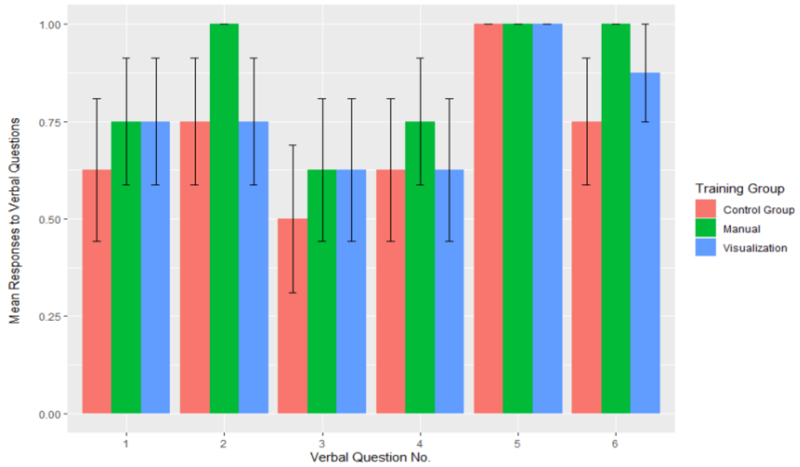

Figure 4. Drivers' verbal response accuracy

3.3. Accuracy of manual responses

The average accuracy of the drivers' manual responses to instructions is illustrated in Figure 5. Overall, the visualization group had higher mean accuracy of manual responses (0.775) than the control group (0.75) and the manual training group (0.725). However, these differences were not statistically significant as a one-way ANOVA revealed that there was no main effect of training group on the accuracy of participants' manual responses ($F = 0.2561$; $p = 0.776$; $\eta2 = 0.02$).

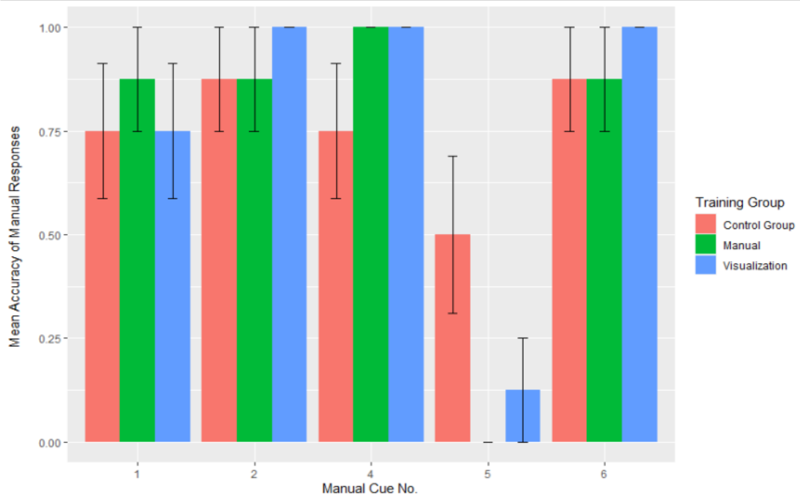

Figure 5. Drivers' manual response accuracy

3.4. Response times for manual responses

On an average, the control group took longer to manually respond (4.18 seconds) than the manual training (3.83 seconds) and visualization training (4 seconds) groups. However, a one-way ANOVA revealed that there was no main effect of training group on the participants' response times for manual responses ($F = 0.2821$; $p = 0.757$; $\eta2 = 0.03$).

4. Discussion

The results of the above analyses indicate an overall increase in knowledge of ACC after training. More specifically, drivers from both the experimental training groups, i.e., those who received the Visualization training and the User Manual training, had significantly improved knowledge and understanding of the ACC system. This outcome underscores the potential importance of training as one significant and viable approach for users' knowledge of these complex vehicle systems.

An outcome of note from this study is that there was no significant difference in level of improvement between the two experimental groups. The visualization training was developed to reduce the density of information provided by user manuals and to simplify the conceptual models of ADAS with the help of illustrations of various states and ways to switch between them. User manuals are generally dense in terms of text, they are relatively inaccessible since looking for specific information about system controls means parsing through an entire user manual, and there is some evidence that drivers do not rely on user manuals for their information [10]. Given these, there was a slight expectation that the visualization training may be more efficient or effective but that was not supported by the results. One possible interpretation of this result is that the abovementioned drawbacks of a user manual may have not manifested enough in this experimental context. The user manual training consisted of excerpts from the user manual and were presented in an accessible and concise manner. Additionally, the experiment required the drivers to specifically read the user manual excerpts. These may have contributed to improved learning. In retrospect, presenting the physical user manual and requiring the users to extract the information may have been an interesting potential arm to this experimental design. In a real-world context there may be a marked advantage of a quicker, visual method for training. This is a potential area for further extending this work to understand how drivers gain information.

When driver knowledge was measured in real time and in the driving context by probing drivers during the drives, the drivers in the experimental groups generally scored more accurately than those in the control groups, but the differences were not significant. The previously discussed outcome, that drivers' knowledge was significantly better in the experimental groups after training, should also have been evident in this secondary measure of knowledge but that was not seen. A potential explanation for this may lie in the design of the experiment itself, and more specifically in the content of the probes. The probed questions were relatively easy and simple, e.g., "What is your current speed?", or "Is ACC currently active?". The specific probe questions that were used for this study may not have been sensitive enough to measure one's deeper understanding of the system.

Similarly, the drivers' manual responses to specific system interaction instructions were more accurate for the visualization group than the user manual group or the control group, but the differences were not significant. As discussed previously, it would not be unreasonable to expect an improved manual response in the experimental drivers given that cohort's improvement in knowledge and understanding after training. However, the current data does not support this. Again, this could be potentially explained by the fact that – just like the verbal probes – the manual instructions were relatively easy and simple (e.g., changing ACC set speed or distance). Most drivers scored at ceiling for manual performance. More complex interactions with the system may have perhaps led to more sensitivity in differentiating driver knowledge from these manual responses. Also, in terms of reaction time or speed of responses, while the experimental groups were slightly quicker at responding to probes, there was no significant difference between groups for this metric. An important learning from this study, from the perspective of empirical experimental approaches, is that the measures chosen to study the impact on drivers' knowledge and understanding of a system is quite critical. It appears that the dependent variables chosen in this study may not have been the best or most sensitive metrics to tease out differences in drivers' understanding. This indeed return to the original issue and the challenges in objectively measuring users' mental models. Future work is recommended in this domain, especially in ascertaining approaches to efficiently, effectively, non-invasively, and quickly measure users' knowledge of vehicle systems.

While this study indeed adds to the evidence about the importance and viability of training as a tool to improve driver knowledge, it did have some important limitations that should be considered when interpreting the outcomes. First, an important limitation is the size and makeup of the study sample. There were 24 participants, and despite aiming for a broader age range, the final participants skewed heavily towards the younger age group. While the limitation of the small sample size is obvious, it is important to also acknowledge the potential impact of a younger-skewing sample. This may have had an impact on the outcomes, including on direct measures such as reaction time, or indirectly by potentially influencing knowledge gain due to differences in technological familiarity or acceptance. A second important limitation is that the only system studied here was ACC. This design decision was made from an experimental control perspective with a primary goal of reducing confounds and focusing on ADAS learning, rather than learning for specific flavors of ADAS. However, we recognize that ACC is vastly different from other ADAS such as LKA, and even more different than the combined functionality of the two (LKA + ACC). Further exploration of the effects of training on drivers' mental models and driver behavior in the context of more complex automation is critical to better understand use and acceptance of these technologies, and to inform design and policy where deployment of such technology is concerned. Another important future research focus would be to examine if these research outcomes generalize, not only to other types of ADAS, but also to higher forms of automation, and to broader user populations.

5. Conclusions

In this study, we examined the effects of training on drivers' use and understanding of vehicle technologies, namely Adaptive Cruise Control (ACC). We evaluated training approaches using a driving simulation platform. "Driver use" was operationalized as actual driver operation of systems in a simulated environment, and 'understanding' as drivers' mental models of the system. Participants were randomly administered one of three training approaches and the impact of training was examined by contrasting driver knowledge (mental model) before and after training, and driver behaviors in terms of system use of real-time responses about system state across three training types.

The study results show that training is associated with improved knowledge about the systems. It also shows differential effects of different approaches to training, with text-based training showing more effectiveness. This data shows no significant improvement in system handling accuracy or performance after training, which may indicate differences in mechanisms between understanding and using a system. Importantly, the results show that training approach may not matter much, but that outcome may be an artifact of the experimental design and experimental context.

These findings have important implications for the design and deployment of these systems. A flawed or incomplete understanding of a system's functionalities may lead to underuse or misuse. Training and other education approaches can help improve drivers' understanding of the systems, resulting in more appropriate and thus safer use of these systems. The results suggest that, from a practical perspective, shorter and more accessible and focused training may hold and advantage over denser, text-based, user manuals, but more work is needed to understand the differences in content and delivery. The results from this study show promise of training and adds to the relatively scarce knowledge-base on research regarding training and education for vehicle automation systems.

6. Acknowledgment

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7. References

1. Bengler, K., Dietmayer, K., Farber, B., Maurer, M., Stiller, C., & Winner, H. Three decades of driver assistance systems: Review and future perspectives. *IEEE Intelligent Transportation Systems Magazine*, 2014. 6(4), 6–22.
2. Merat, N., & Lee, J. D. (2012). Preface to the special section on human factors and automation in vehicles: Designing highly automated vehicles with the driver in mind. *Human factors, 54(5), 681-686.*
3. Carroll, J. M., & Olson, J. R. (1987). Mental Models in Human-Computer Interaction. Research Issues about What the User of Software Knows. *Workshop on Software Human Factors: Users' Mental Models (Washington, District of Columbia, May 15-16, 1984).*
4. Krampell M, Solís-Marcos I, Hjälmdahl M. (2018) Driving automation state-of-mind: Using training to instigate rapid mental model development. *Appl Ergon. 2020;83(August 2018). doi:10.1016/j.apergo.2019.102986*
5. Pradhan, A.K., Divekar, G., Masserang, K., Romoser, M., Zafian, T., Blomberg, R.D., Thomas, F.D., Reagan, I., Knodler, M., Pollatsek, A., Fisher, D.L. (2011) The Effects of Focused Attention Training (FOCAL) on the Duration of Novice Drivers' Glances Inside the Vehicle. *Ergonomics*, Vol 54; Issue 1; 917-931
6. Pradhan, AK, Sullivan J, Schwarz C, Feng F, Bao S. (2019) Training and Education: Human Factors Considerations for Automated Driving Systems. *In: Road Vehicle Automation 5. Springer; 2018:77-84.*
7. Pradhan, AK, Pai, G, Hungund, A, Pamarthi, J (under preparation) Does Training Improve Users' Mental Models about Adaptive Cruise Control?
8. Pradhan, A. K., Pai, G., Radadiya, J., Knodler Jr, M. A., Fitzpatrick, C., & Horrey, W. J. (2020). Proposed framework for identifying and predicting operator errors when using advanced vehicle technologies. *Transportation research record*, *2674*(10), 105-113.
9. Jian, J. Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an empirically determined scale of trust in automated systems. *International journal of cognitive ergonomics*, *4*(1), 53-71.
10. Mehlenbacher, B., Wogalter, M. S., & Laughery, K. R. (2002, September). On the reading of product owner's manuals: Perceptions and product complexity. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 46, No. 6, pp. 730-734). Sage CA: Los Angeles, CA: SAGE Publications.