

# The Effects of a Driver Monitoring System on Drivers' Trust, Satisfaction, and Performance with an Automated Driving System

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## **ABSTRACT**

This study was performed with the goal of delineating how drivers' interactions with an Automated Driving System were affected by a Driver Monitoring System (DMS), which provided alerts to the driver when he or she became inattentive to the driving environment. There were two specific research questions. The first was centered on addressing how drivers' trust and satisfaction with an Automated Driving System was affected by a DMS. The second was centered on addressing how drivers' abilities to detect changes in the driving environment that required intervention were affected by the presence of a DMS.

Data were collected from fifty-six drivers during a test-track experiment with an Automated Driving System prototype that was equipped with a DMS. DMS attention prompt conditions were treated as the independent variable and trust, satisfaction, and driver performance during the experimenter triggered lane drifts were treated as dependent variables.

The findings of this investigation suggested that drivers who receive attention prompts from a DMS have lower levels of trust and satisfaction with the Automated Driving System compared to drivers who do not receive attention prompts from a DMS. While the DMS may result in lower levels of trust and satisfaction, the DMS may help drivers detect changes in the driving environment that require attention. Specifically, drivers who received attention prompts after 7 consecutive seconds of inattention were 5 times more likely to react to a lane drift with no alert compared to drivers who did not receive attention prompts at all.

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## **LIST OF ABBREVIATIONS**

Adaptive Cruise Control	ACC
Advanced Driver Assistance System	ADAS
Analysis of Variance	ANOVA
Confidence Interval	C.I.
Driver Monitoring System	DMS
National Highway Traffic Safety Administration	NHTSA
Original Equipment Manufactures	OEM
Odds Ratio	OR
Society of Automotive Engineers	SAE



# **CHAPTER 1: INTRODUCTION**

## **1.1 Motivation**

In 2013 there were 32,179 fatalities on U.S. highways (The National Highway Traffic Safety Administration NHTSA, 2013). Of these, driver error played a role in 94% of crashes (Singh, 2015). In this context, the majority of crashes, injuries, and fatalities could be preventable. Researchers and Original Equipment Manufacturers (OEMs) have begun exploring Automated Driving Systems. These systems have the potential to improve highway safety and reduce the number of fatalities that occur as a result of driver error (Trimble, Bishop, Morgan, & Blanco, 2014).

## **1.2 Automation**

Automation is defined as the “mechanical and electrical accomplishment of work,” (Wickens & Hollands, 2000 p. 538). This often replaces tasks that humans are typically required to perform during the execution of a job, skill, or duty. Three components encapsulate the definition of automation: 1) its intentions, 2) the human functions it substitutes, and 3) the advantages and disadvantages demonstrated in the interaction between humans and automated apparatuses (Wickens & Hollands, 2000 p. 538).

Wickens and Hollands (2000) outline four categories of automation purposes:

1. The first purpose for using automation is to complete functions that the human is incapable of completing due to human limitations and/or safety concerns. In this category, automation is both necessary and required.
2. The second purpose for using automation is to take over functions when humans would otherwise perform poorly.

3. The third purpose for using automation is to supplement or support the human during times in which they have limitations.
4. The fourth purpose for using automation is centered on economic need. There may be instances in which it is more expensive for the human to complete the task as opposed to automating the task.

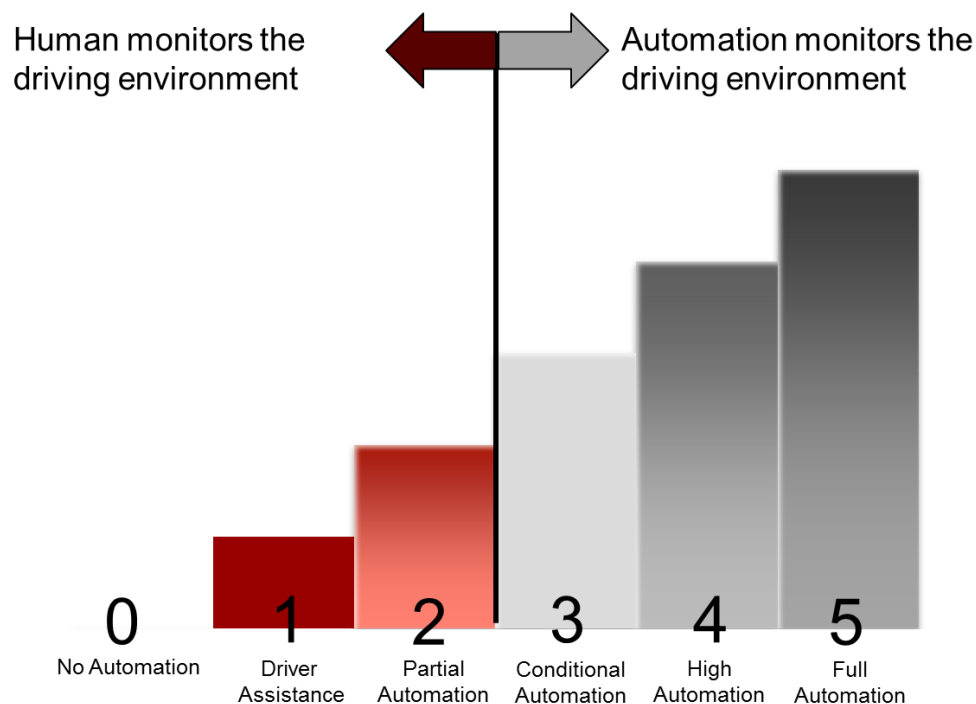
Parasuraman, Sheridan, and Wickens (2000) delineate four primary types of automated systems, including the following: 1) information acquisition, 2) information analysis, 3) decision selection, and 4) action implementation. Parasuraman et al., (2000) also noted that an additional type of automation is for the purpose of monitoring other automated systems. These categories are not necessarily mutually exclusive, meaning that a single automated system can fall into more than one category provided that it performs multiple functions (Hoff & Bashir, 2015).

### **1.3 Automated Driving Systems**

Automated Driving Systems are increasingly present within today's automobiles and alternate forms of transportation. Within the context of automobiles, assistive automated systems such as Adaptive Cruise Control (ACC) and Lane Keep Assist have been developed and implemented in an attempt to relieve the driver of longitudinal and lateral vehicle controls under certain driving scenarios. These two systems use data collected from sensors and cameras in order to control the longitudinal and lateral vehicle functions. Adaptive Cruise Control uses sensors located on the front bumper of the vehicle to detect other lead vehicles. This system detects the presence of a slower moving vehicle and it communicates with the engine controller to automatically adjust speed to accommodate the slower moving vehicle. Lane Keep Assist uses cameras that are designed to detect lane markings in order to center and keep the vehicle in the lane.

Adaptive Cruise Control and Lane Keep Assist change the role of the driver from an active controller of the dynamic driving task to an automation supervisor. The Automated Driving System uses automation to implement actions that were once performed by the driver. Using Wickens and Hollands (2000) classification for automation, current Automated Driving Systems serve the purpose of taking over functions that drivers perform poorly and supplementing the driver where they have limitations. This may potentially improve highway safety by supporting the driver under different driving situations (Trimble et al., 2014).

The Society of Automotive Engineers (SAE) describes six levels of Automated Driving Systems (SAE J3016). The SAE levels begin at Level 0 and increase in terms of the role of automation and decrease in terms of driver control (see Figure 1).



**Figure 1. SAE Levels of Automated Driving Systems (Adapted from SAE J3016)**

Original Equipment Manufacturers are currently producing vehicles equipped with Partial Automation. Under certain driving conditions the dynamic driving task (i.e., longitudinal

and lateral vehicle functions) is automated. The driver is responsible for determining when it is appropriate to activate the Automated Driving System. Additionally, the driver is expected to constantly monitor the driving environment and automation status as he/she is expected to be available to take control of the longitudinal and lateral vehicle functions at any point in time under limited notice (SAE J3016).

However, humans generally do a poor job at monitoring the performance of an automated system over a prolonged period of time (Fitts & Posner, 1967). Recent research on human performance in Automated Driving Systems suggest that drivers are likely to engage in non-driving tasks while the automation is activated (Blanco, Atwood, Vasquez, Trimble, Fitchett, Radlbeck...& Morgan, 2015). As drivers detach from monitoring the driving environment and automation status, they may fail to detect changes in the driving environment and automation status that require human intervention (Blanco et al., 2015). Results from driving simulator studies have yielded similar results, suggesting that Automated Driving Systems may have deleterious effects on a driver's situation awareness and performance during take-over requests (Merat, Jamson, Lai, Daly, & Carsten, 2014; Gold, Dambock, Lorenz, & Bengler, 2013).

This research suggests that it may not be reasonable to expect drivers to constantly monitor the driving environment and automation status while the Automated Driving System is activated (Merat et al., 2014; Gold et al., 2013; Blanco et al., 2015). Additionally, the driver requires time to regain situation awareness and resume control of the longitudinal and lateral vehicle functions during a take-over request. In order to help the driver monitor the driving environment and automation status to an appropriate level, OEMs have begun exploring Driver Monitoring Systems (DMSs). These systems are designed to monitor the driver's attention to the driving environment and alert the driver when the driver is identified as inattentive. These alerts

are intended to elicit the driver to transition his/her attention to the driving environment. Ultimately this may prevent decrements in the driver's situation awareness and may result in quicker responses to take-over requests.

Research on how drivers interact with Automated Driving Systems equipped with DMSs is limited. The majority of published research on DMSs is aimed at addressing methods for detecting driver drowsiness and driver distraction (Vicente, Huang, Xiong, De la Torre, Zhang, & Levi, 2015; Meshram, Auti, & Agrawal, 2015; Teyeb, Jemai, Zaied, & ben Amar, 2015; He, Li, Fan, & Fi, 2014; Masala & Grasso, 2014; Brandt, Stemmer, & Rakotonirainy, 2004; Ji, Zhu, & Lan, 2004; Rongben, Lie, Bingliang, & Lisheng, 2004; Smith, Shah, & Lobo, 2003; Ji & Yang, 2002). The paucity of research on driver interaction with DMSs may be attributed to the proprietary nature of these systems. A research investigation evaluating heavy vehicle drivers' performance with a driver drowsiness detection system suggested that this system might enhance drivers' performance (Blanco, Bocanegra, Morgan, Fitch, Medina, Olson...Green, 2009). Similarly, researchers have found that providing drivers with real-time feedback on their level of drowsiness improves driver performance (Aidman, Chadunow, Johnson, & Reece, 2015). Additionally, research suggests that DMSs are effective at increasing drivers' attention to the driving environment (Blanco et al., 2015). However, how DMSs affect drivers' trust and satisfaction with the Automated Driving System has yet to be delineated. Additionally, research evaluating how DMSs affect drivers' ability to detect changes in the driving environment has yet to be explored.

## **1.4 Trust in Automation**

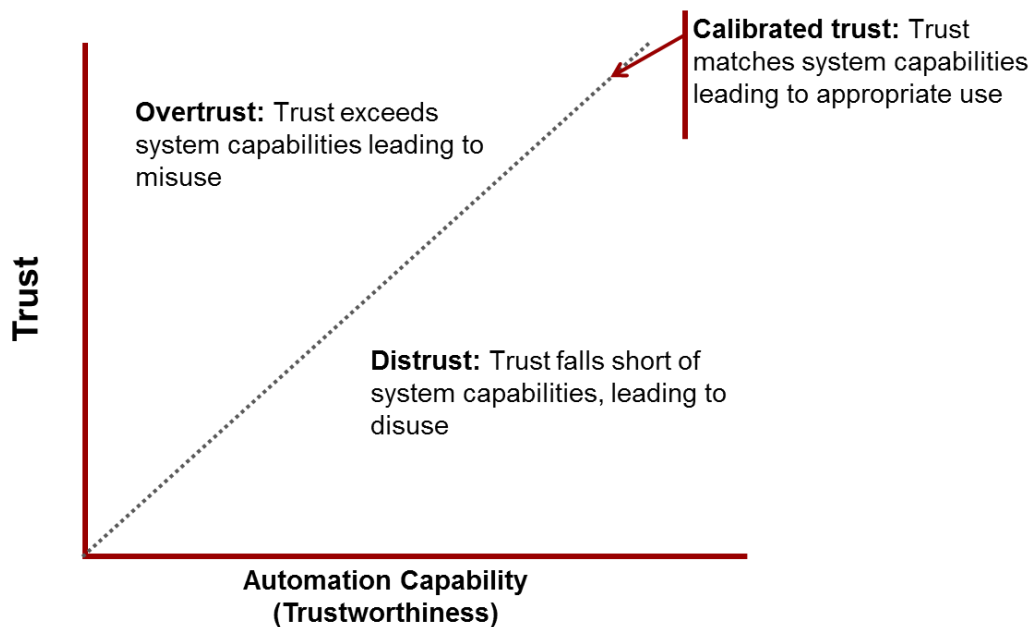
Trust can be defined as “the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability,” (Lee & See, 2004). An agent can

refer to either automation or another person that interacts with the environment on behalf of the person. Trust mediates the interactions and relationships between people and automation as well as between people (Sheridan & Hennessy, 1984). People have the tendency to rely on automation that is deemed trustworthy and reject automation that is deemed untrustworthy.

By guiding reliance, trust helps overcome the cognitive complexity faced in managing increasing levels of automation (Lee & See, 2004). Misuse and disuse in automation lead to inappropriate reliance (Lee & See, 2004). Fostering an appropriate level of trust is crucial to avoiding misuse and disuse (Wicks, Berman, & Jones, 1999). Hoff and Bashir (2015) provide two examples of misuse and disuse. The *Costa Concordia* cruise ship disaster that killed 32 passengers in January 2012, may have occurred as a result of the captain's lack of trust in the ship's automated navigation system. Accident investigations revealed that the captain diverged from the ship's preprogrammed route prior to crashing into a shallow reef that ultimately led to the sinking (Levs, 2012). The crash of Turkish Airlines Flight 1951 in February 2009, may be due to the pilots' overtrust in the automation. This crash resulted in the death of nine people, including all three pilots. Accident investigations revealed that the crash was partially caused by the pilots' continued reliance in the plane's automatic pilot after an altitude-measuring instrument failed ("Faulty Reading Helped," 2009). These two cases illustrate the potential negative effects of disuse and misuse in automation.

The concept of trust is important when considering drivers' interactions with Automated Driving Systems because trust has been demonstrated to guide reliance (Lee & See, 2004). If drivers' do not trust the Automated Driving System, they may not use the system even during scenarios where the system would provide needed support to the driver. Conversely, if drivers' trust exceeds the capabilities of the Automated Driving System, they may misuse or abuse the

system. Drivers need to be able to calibrate their trust to the Automated Driving System's abilities. Calibration is defined as the "correspondence between a person's trust in the automation and the automation's capabilities" (Lee & Moray, 1994; Muir, 1987). Overtrust is the result of poor calibration in which trust exceeds the systems capabilities, while distrust results when trust falls short of the systems capabilities. In Figure 2, appropriate calibration occurs at the diagonal line; above this line represents overtrust and below this line represents distrust.



**Figure 2. Trust in Automation, Calibrated Trust, Over trust, and Distrust (Adapted from Lee & See 2004).**

Specific types of automation failures have different effects on trust. In particular, false alarms and misses generally have different effects on trust (Sanchez, 2006). False alarms have been found to reduce operator compliance more than reliance, while system misses have been demonstrated to reduce reliance more than compliance (Davenport & Bustamante, 2010; Dixon, 2007; Dixon & Wickens, 2006). For example, if drivers receive false alarms, they may fail to use the Automated Driving System appropriately and if drivers experience system misses they may feel that the Automated Driving System is unreliable.

Additionally, false alarms and misses may affect trust differently (Hoff & Bashir, 2015). Hoff and Bashir (2015) speculate that because false alarms tend to be more prevalent than system misses, this may require the operator to put effort into unnecessary investigations of the system status, ultimately affecting subjective feelings of trust to a greater extent than system misses. However, some research has suggested that false alarms and misses have similar effects on trust (Madhavan et al., 2006; Rovira & Parasuraman, 2010). Additionally, two research investigations using a flight simulator (Stanton, Ragsdale, & Bustamante, 2009) and an unmanned aerial vehicle (Davenport & Bustamante) demonstrated that participants trusted false-alarm prone systems more than miss-prone systems. Hoff and Bashir (2015) speculate that the differences in results obtained from these research investigations may be attributed to the consequences associated with each type of error in the specific context studied. For example, while a false alarm for a Collision Warning System might be inconvenient, a system miss may be catastrophic resulting in a crash.

Research has also indicated that the presence of false alarms can create a cry wolf effect (Breznitz, 2013). The cry wolf effect occurs when excessive alarms lead to distrust and disuse in an alarm system. Ultimately, this distrust or disuse can lead to a disregard of (or a delayed response to) true alarms (Lee & See, 2004; Parasuraman & Riley, 1997).

In the context of Advanced Driver Assistance Systems (ADAS) such as Forward Collision Warning, Blind Spot Warning, and Lane Departure Warning, research has demonstrated that drivers' trust in these systems decrease when they experience false alarms (Abe, Ioth, & Tanaka, 2002; Abe & Richardson, 2005; Donmez, Boyle, Lee, & McGehee, 2006). This may ultimately limit the effectiveness of the true warnings (Lees & Lee, 2007).



Research centered on drivers' interactions with Automated Driving Systems suggests that drivers generally have a high level of trust in Automated Driving Systems (Kircher, Larsson, & Hultgren, 2013); however, trust tends to decrease after drivers experience automation failures (Blanco et al., 2015). When drivers overtrust the Automated Driving System, they tend to take longer to respond to take-over requests (Payre, Cestac, Delhomme, 2015). Conversely, when drivers distrust the Automated Driving System, they tend to monitor the driving environment more (Ka-Jun Mok, Sirkin, Sibi, Miller, & Ju, 2014). This suggests that drivers are able to calibrate their trust according to the automations capabilities.

### **1.5 Study Objectives and Hypotheses**

The goal of the present study is to determine how drivers' interactions with an Automated Driving System are affected by a DMS. This study answers two specific research questions:

1. How does a DMS affect drivers' trust and satisfaction with an Automated Driving System?
2. How does a DMS affect drivers' abilities to detect changes in the driving environment that require driver intervention?

Three hypotheses were developed to address these two research questions.

1. Drivers who receive attention prompts from a DMS will report lower levels of trust with an Automated Driving System compared to drivers who do not receive alerts from a DMS. Specifically, as the number of false alarms from the DMS prompting system increase, driver trust in the Automated Driving System will decrease.
2. Drivers who receive attention prompts from a DMS will report lower levels of satisfaction with an Automated Driving System compared to drivers who do not receive

alerts from a DMS. Specifically, as the number of false alarms from the DMS prompting system increase, driver satisfaction with the Automated Driving System will decrease.

3. Drivers who receive attention prompts from a DMS will be more likely to detect changes in the driver environment that require driver intervention compared to drivers who do not receive alerts from a DMS.

## CHAPTER 2: METHOD

### 2.1 Study Variables

#### 2.1.1 Independent Variables

A 3 x 3 mixed factor design was used. In order to address our research questions, which are centered on how drivers' trust, satisfaction, and performance with the Automated Driving System are affected by the DMS, *attention prompt condition* and *lane drift type* were treated as the independent variable for the present study.

##### *Attention Prompt Condition*

This between-subjects independent variable consists of three levels:

1. 2-seconds: drivers who experienced attention prompts from the DMS after 2 consecutive seconds of inattention to the driving environment.
2. 7-seconds: drivers who experienced attention prompts from the DMS after 7 consecutive seconds of inattention to the driving environment.
3. No prompts: drivers did not experience any attention prompts from the DMS regardless of their attention level to the dynamic driving task.

##### *Lane Drift Type*

This within-subject independent variable consists of three levels:

1. Alert: during one of the three driving sessions, the vehicle drifted from the lane and participants received a visual and haptic alert.
2. No alert: during one of the three driving sessions, the vehicle drifted from the lane and participants did not receive an alert.

3. None: during one of the three driving sessions, participants did not experience a lane drift.

### ***2.1.2 Dependent Variables***

Three dependent variables were used to address the two research questions. The first dependent measure was related to drivers' after-experience trust ratings that were captured at the conclusion of each driving session. The second dependent measure was related to drivers' after-experience satisfaction ratings that were captured at the conclusion of each driving session. The third dependent measure was related to drivers' performance during the lane drift.

1. After-Experience Trust Ratings: At the conclusion of each of the three driving sessions, drivers were asked to rate their level of trust in the Automated Driving System on 6 questions that were related to trust. Responses were reported on a 7-point Likert-type scale, with "1" corresponding to strongly disagree and "7" corresponding to strongly agree.
2. After Experience Satisfaction Ratings: At the conclusion of each of the three driving sessions, drivers were asked to rate their level of satisfaction with the Automated Driving System on 3 questions and 5 statements related to satisfaction. Responses were reported on a 7-point Likert-type scale, with "1" corresponding to strongly disagree and "7" corresponding to strongly agree.
3. Performance during lane drift: This dependent variable consisted of three performance measures.
  - a. Did the driver react to the lane drift? This was defined as whether the driver looked forward during the lane drift without experimenter instruction. This was treated as a binary variable (i.e., yes or no).

- b. Did the driver regain control? This was defined as whether the driver took control of the steering wheel during the lane drift without experimenter instruction. This was treated as a binary variable (i.e., yes or no).
- c. Did the vehicle depart from the lane? This was defined as whether the vehicle exited the lane. This was treated as a binary variable (i.e., yes or no).

## **2.2 Automated Driving System Data Set**

Data for this study were previously collected as part of the Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts (NHTSA Contract DTNH22-11-D-00235, Task Order 11; see Blanco et al., 2015). During NHTSA's study, fifty-six participants drove a Level 2 Automated Driving System on a controlled test track for three 1-hour sessions. This Automated Driving System consisted of ACC, a prototype Lane Centering system, and a prototype DMS. The DMS monitored drivers' attention to the driving environment and provided attention prompts when the driver was identified as inattentive.

Drivers were asked to engage in visually intensive non-driving tasks using a tablet computer. Drivers were presented with three types of non-driving tasks to complete with the tablet computer: navigation, email, and web browsing. A total of up to ninety different non-driving tasks, thirty in each category, were completed. These tasks were similar in terms of the visual and manual demands required of the driver and were presented in a random order. Tasks were detailed on a notecard. The in-vehicle experimenter passed the task cards to the driver.

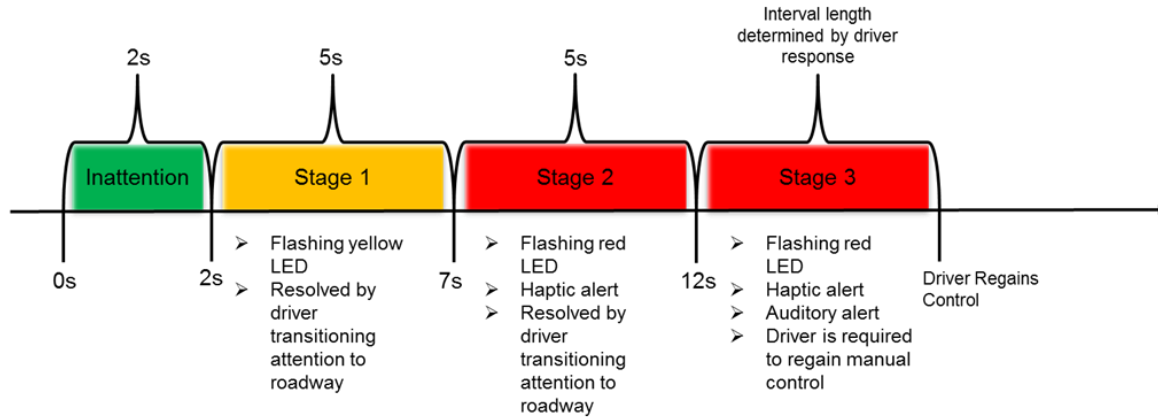
### ***2.2.1 Attention Prompts from the Driver Monitoring System***

Through a between-subjects design, drivers experienced one of three types of attention prompts from the DMS. Eighteen drivers experienced attention prompts from the DMS when they stopped monitoring the driving environment for 2 consecutive seconds. Twenty-one drivers

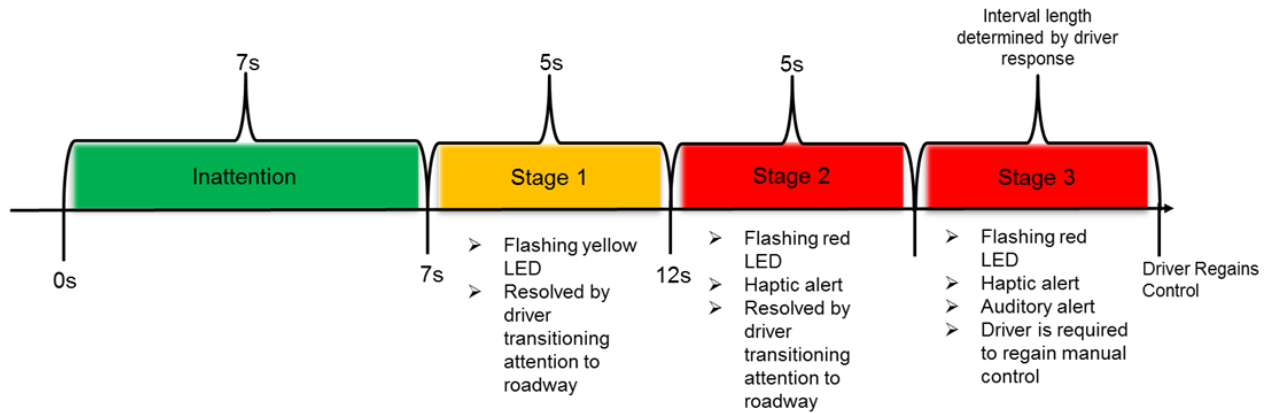
experienced attention prompts from the DMS when they stopped monitoring the driving environment for 7 consecutive seconds. Seventeen drivers did not experience any attention prompts from the DMS. This was a baseline measure for how drivers interacted with an Automated Driving System without a DMS.

The attention prompts were composed of staged intervals increasing in severity (see Figure 3). During Stage 1, drivers experienced a yellow visual alert. If the driver failed to transition his or her attention to the driving environment, the attention prompt progressed to Stage 2. During Stage 2, drivers experienced a red visual alert and a haptic alert. If the driver failed to transition his or her attention to the driving environment, the attention prompt progressed to Stage 3. During Stage 3, drivers experienced a red visual alert, a haptic alert, and an auditory alert. Stage 3 lasted until the driver responded by regaining control of the steering wheel. Note that drivers were not informed how the DMS worked or how to respond to the prompts because OEMs are not required to provide drivers with instruction and training with Level 2 Automated Driving Systems.

### Prompt Progression for 2-second Prompt Condition



### Prompt Progression for 7-second Prompt Condition



**Figure 3. Attention Prompt Progression for 2 and 7 Second Attention Prompt Conditions (Blanco et al., 2015)**

#### **2.2.2 Experimenter Triggered Lane Drifts**

Two types of experimenter triggered lane drifts were presented: alert and no alert. Upon triggering the lane drift, the vehicle would depart from the lane within approximately 3 seconds. During the lane drift with an alert, the experimenter triggered the vehicle to drift from the lane and drivers were alerted to this issue through a visual and haptic alert. During the lane drift with no alert, the experimenter triggered the vehicle to drift from the lane; however, drivers were not alerted to this issue. Note that during these lane drifts, the DMS stopped issuing prompts for drivers in the 2 and 7 second prompt conditions. During the lane drift with no alert, this means

that neither the vehicle alerted to driver to the lane drift nor did the DMS prompt drivers to transition their attention to the driving environment if they were inattentive. Drivers also experienced one driving session in which they did not experience a lane drift. Specifically, drivers experienced one driving session with a lane drift with an alert, one driving session with a lane drift with no alert, and one driving session with no lane drift.

### ***2.2.3 After-Experience Trust and Satisfaction Scales***

At the conclusion of each of the three driving sessions, drivers were asked to complete after-experience trust and satisfaction surveys.

Trust scales used in the evaluation of automated systems were reviewed (Lee & Moray, 1994; Luz 2009; Jian, Bisantz & Drudy, 2000) in order to develop the trust scales that were used in this study. Key phrases related to trust (i.e., overall trust, perceived reliability, perceived competence under automated control, and perceived understandability) were identified from Luz's (2009) 19 question trust scale. The wording of the phrases used by Luz (2009) were modified for the present investigation.

Drivers were asked to respond to the following questions as part of the after-experiences trust survey (see Appendix A for full survey). Responses to these statements were based on a 7-point Likert-type scale with options ranging from "1," which corresponded to strongly disagree, to "7," which corresponded to strongly agree.

T1: I can rely on the automated system to function properly while I am doing something else.

T2: The automated system provided alerts when needed.

T3: The automated system gave false alerts.

T4: The automated system is dependable.



T5: I am familiar with the automated system.

T6: I trust the automated system.

A satisfaction survey was developed for this investigation. Drivers were asked to respond to the following questions/statements as part of the after-experience satisfaction survey (see Appendix B for full survey). Responses to these statements were based on a 7-point Likert-type scale with options ranging from “1,” which corresponded to strongly disagree, to “7,” which corresponded to strongly agree.

S1: Overall, how satisfied are you with the automated system?

S2: How satisfied were you with the number of alerts provided?

S3: How satisfied were you with the types of alerts provided?

S4: The automated system’s alerts provided sufficient time to make a decision.

S5: The automated system’s alerts provided sufficient information to make a decision.

S6: I would use this type of automated system during my normal driving.

S7: I would like to have this type of automated system as part of my current vehicle.

S8: I would like to have this type of automated system as part of a future vehicle.

#### ***2.2.4 False Alarms from the DMS***

A team of data reductions reviewed all of the attention prompts that drivers experienced during the experiment. The prompts were coded as either true or false alerts. Instances where the driver was inattentive to the driving environment during the 2 seconds or 7 seconds (depending upon the attention prompt condition) were coded as true alerts. Instances where the driver was attentive to the driving environment during the 2 seconds or 7 seconds (depending upon the attention prompt condition) prior to the attention prompt were coded as false alerts. Additionally,

instances in which the attention prompt progressed to stage 2 or stage 3 after the driver had already transitioned his or her attention to the driving environment were also coded as false alerts.

## **2.3 Data Analysis**

All statistical analyses were performed using JMP Pro, version 11.0.0. All statistical tests were performed using an alpha level of .05.

### ***2.3.1 After-Experience Trust and Satisfaction Scales***

Because the trust scales were adapted from those used in a previous research investigation (Luz, 2009) and the satisfaction scales were developed for this investigation, an item analysis was performed. Cronbach's alpha was used to determine internal consistency and correlations between the individual scale items were calculated.

When analyzing the effects of the attention prompt condition on driver trust and satisfaction, the Shapiro-Wilks test revealed that the residuals were not normally distributed. The Kruskal-Wallis test was used to analyze the data after-experience trust and satisfaction scales. This test is the non-parametric equivalent of a one-way ANOVA. The Steel-Dwass test was used for a post-hoc analysis to determine which attention prompt condition group(s) were statistically different. This test is the non-parametric equivalent of Tukey's HSD and can be used with unequal sample sizes (Critchlow & Flinger, 1991).

Any differences found between drivers in the 2-second attention prompt condition and the 7-second attention prompt condition on the trust and satisfaction ratings were further analyzed. Specifically, the number of false alerts and the total number of alerts from the DMS that drivers experienced in the 2-second and 7-second attention prompt conditions were

analyzed. Equal variances between these two groups were not met. As such, the Wilcoxon test was selected to analyze the data. Drivers in the no prompt condition were excluded from this analysis as they did not experience attention prompts from the DMS and did not experience any false alerts.

### ***2.3.2 Performance during Lane Drift***

Logistic regression was used to analyze driver performance during the lane drift. This was used to determine if more drivers who received attention prompts from the DMS reacted, regained control, and drifted from the lane compared to drivers who did not receive attention prompts from the DMS. Odds Ratios (O.R.) were then used to determine the likelihood that drivers who received attention prompts from the DMS reacted, regained control, and drifted from the lane in comparison to drivers who did not receive attention prompts from the DMS.

Any differences found between drivers in the 2-second attention prompt condition and 7-second attention prompt condition were further analyzed. Specifically, the number of false alerts and total number of attention prompts drivers experienced prior to the lane drift in the 2-second and 7-second attention prompt conditions were analyzed. Equal variances between these two groups were not met. As such, the Wilcoxon test was selected to analyze the data. Drivers in the no prompt condition were excluded from this analysis as they did not experience attention prompts from the DMS and did not experience any false alerts.

## CHAPTER 3: RESULTS

### 3.1 After-Experience Trust Scales

#### 3.1.1 Overview of the After-Experience Trust Scales and Results

Table 1 below depicts a summary of the results for the after experience trust scales. Only significant results from this table are reported in the analysis section.

*Table 1. Summary Table for Trust Analysis*

Trust Statement	Attention Prompt Condition	Take-Away
T1: I can rely on the automated system.	Significant	<b>Drivers who received prompts from the DMS rated the Automated Driving System as less reliable.</b>
T2: The automated system provided alerts when needed.	Not Significant	Both drivers who received prompts and drivers who did not receive prompts from the DMS felt that the Automated Driving System provided alerts when needed.
T3: The automated system gave false alerts.	Significant	<b>Drivers who received prompts from the DMS indicated receiving more false alerts.</b>
T4: The automated system is dependable.	Not Significant	Both drivers who received prompts and drivers who did not receive prompts rated the Automated Driving System as dependable
T5: I am familiar with the automated system.	Not Significant	Both drivers who received prompts and drivers who did not receive prompts felt familiar with the

		Automated Driving System
		<b>Drivers who received prompts from the DMS indicated lower levels of trust with the Automated Driving System.</b>
T6: I trust the automated system.	<b>Significant</b>	

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Table 2 displays the described statistics for responses to the trust statements.

***Table 2. Summary of Descriptive Statistics for the After-Experience Trust Ratings by Attention Prompt Condition***

Trust Statement	2-Seconds				7-Seconds				No prompts			
	$\mu$	S.D.	Min	Max	$\mu$	S.D.	Min	Max	$\mu$	S.D.	Min	Max
<b>T1</b>	5.3	1.3	2	7	5.8	1.3	1	7	6.3	0.9	4	7
<b>T2</b>	4.9	1.7	1	7	5.8	1.4	1	7	6.1	0.9	4	7
<b>T3</b>	4.5	2.0	1	7	4.7	1.9	1	7	2.5	1.8	1	7
<b>T4</b>	5.2	1.3	2	7	5.7	1.1	2	7	6.1	1.0	3	7
<b>T5</b>	5.6	1.1	2	7	5.8	1.2	1	7	6.0	0.9	3	7
<b>T6</b>	5.3	1.3	2	7	5.5	1.5	1	7	6.3	0.7	4	7

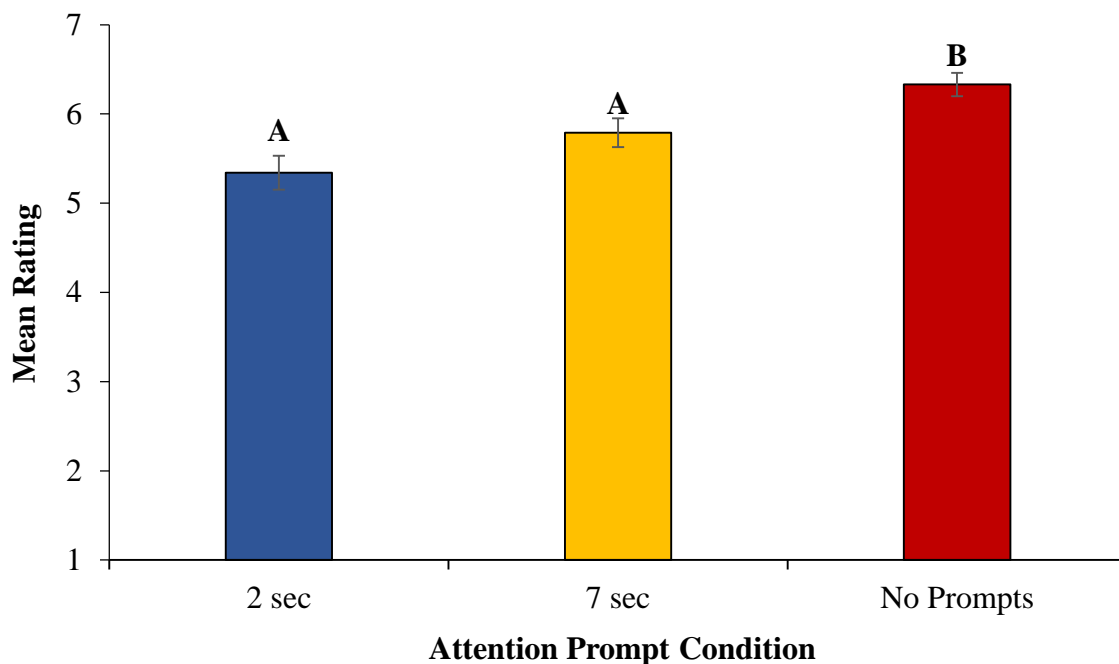
Cronbach's alpha was 0.77, which indicates acceptable internal consistency among the trust statements. Correlations between the trust statements can be found in Appendix C.

### ***3.1.2 Analysis of After-Experience Trust Ratings***

The Kruskal-Wallis test was conducted to determine whether driver trust ratings varied as a function of attention prompt condition. Driver ratings varied as a function of attention prompt condition on three of the trust statements: 1) "I can rely on the automated system." 2) "The automated system gave false alerts." and 3) "I trust the automated system."

*“I can rely on the automated system.”*

The Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2(2) = 19.64, p < 0.001$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS rated the system as less reliable than drivers who did not receive attention prompts from the DMS (see Figure 4 shown below).



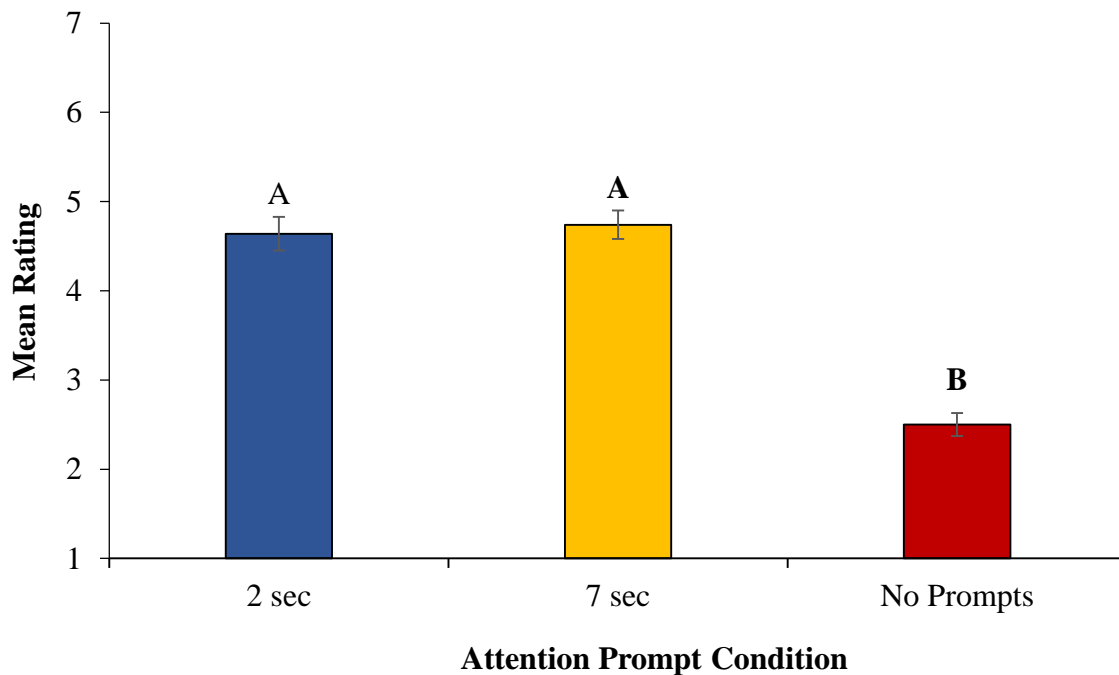
**Figure 4. Mean and Standard Error Bar Plot for After Experience Trust Statement “I Can Rely on the Automated System,” from 1 Strongly Disagree to 7 Strongly Agree. Different Letters Represent a Statistically Significant Difference.**

Specifically, drivers who received attention prompts after 2-seconds of inattention had significantly lower ratings on this trust statement compared to drivers who did not receive attention prompts from the driver monitoring system ( $Z = 4.72, p < 0.0001$ ). Similarly, drivers who received attention prompts after 7-seconds of inattention had significantly lower ratings on

this trust statement compared to drivers who did not receive attention prompts from the DMS ( $Z = 2.76, p = 0.0157$ ).

*“The automated system gave false alerts.”*

Results from the Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2(2) = 34.78, p < 0.001$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS indicated that they received more false alerts than drivers who did not receive attention prompts from the DMS (see Figure 5).



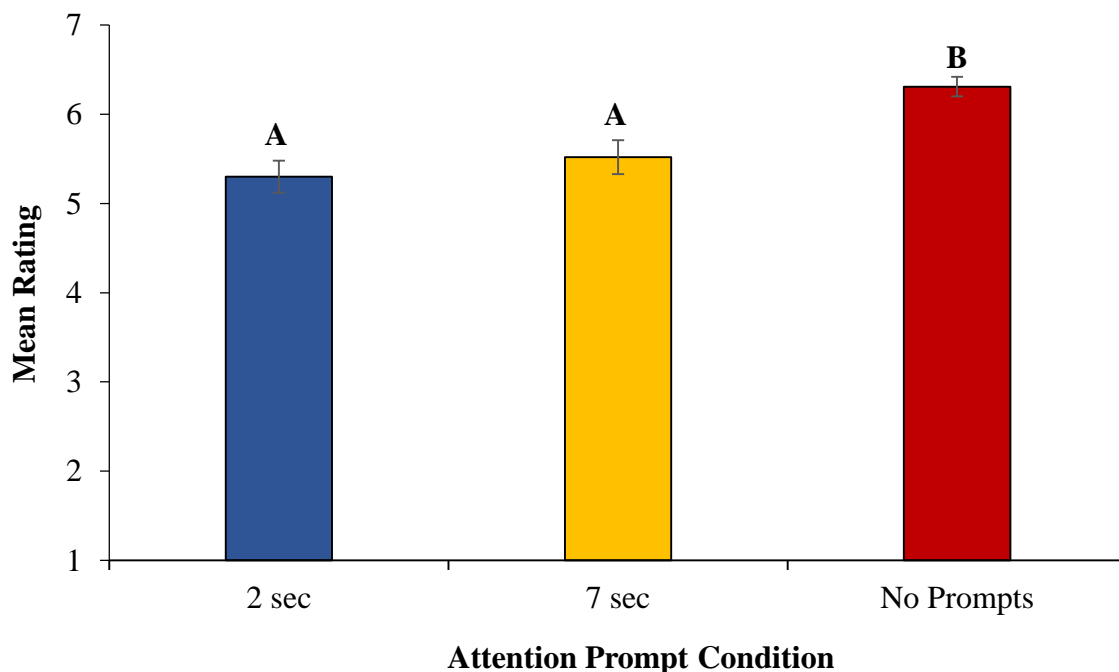
**Figure 5. Mean and Standard Error Bar Plot for After Experience Trust Statement “The Automated System Gave False Alerts,” from 1 Strongly Disagree to 7 Strongly Agree. Different Letters Represent a Statistically Significant Difference.**

Specifically, drivers who received attention prompts after 2-seconds of inattention indicated receiving more false alerts compared to drivers who did not receive attention prompts from the DMS ( $Z = -4.73, p < 0.0001$ ). Similarly, drivers who received attention prompts after

7-seconds of inattention indicated receiving more false alerts compared to drivers who did not receive attention prompts from DMS ( $Z = -5.51, p < 0.0001$ ).

*“I trust the automated system.”*

Results from the Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2(2) = 18.61, p < 0.0001$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS had lower levels of trust in the automated driving system than drivers who did not receive attention prompts from the DMS (see Figure 6 shown below).



**Figure 6. Mean and Standard Error Bar Plot for After Experience Trust Statement “I Trust the Automated System,” from 1 Strongly Disagree to 7 Strongly Agree. Different Letters Represent a Statistically Significant Difference.**

Specifically, drivers who received attention prompts after 2-seconds of inattention had significantly lower ratings on this trust statement compared to drivers who did not receive



attention prompts from the DMS ( $Z = 4.31$ ,  $p < 0.0001$ ). Similarly, drivers who received attention prompts after 7-seconds of inattention had significantly lower ratings on this trust statement compared to drivers who did not receive attention prompts from the DMS ( $Z = 2.96$ ,  $p = 0.0085$ ).

## 3.2 After-Experience Satisfaction Scales

### 3.2.1 Overview of the After-Experience Satisfaction Scales and Results

Table 3 below depicts a summary of the results for the after experience satisfaction scales. Only significant results from this table are reported in the analysis section.

*Table 3. Summary Table for Satisfaction Analysis*

Satisfaction Question/Statement	Attention Prompt Condition	Take-Away
S1:How satisfied were you with the automated system?	Significant	<b>Drivers who received attention prompts from the DMS were less satisfied with the Automated Driving System</b>
S2:How satisfied were you with the number of alerts?	Significant	<b>Drivers who received attention prompts from the DMS after 2-seconds of inattention were less satisfied with the number of alerts compared to drivers who received attention prompts from the DMS after 7-seconds of inattention and drivers who did not receive attention prompts.</b>
S3: How satisfied were you with the types of alerts?	Not Significant	Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS were satisfied with the different types of alerts.

S4:The automated system's alerts provided sufficient time to make a decision.	Not Significant	Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS felt that the Automated Driving System's alerts provided enough time to make a decision.
S5:The automated system's alerts provided sufficient information to make a decision.	Significant	<b>Drivers who received attention prompts after 2-seconds of inattention were less satisfied with the information provided by the alerts than drivers who did not receive attention prompts from the DMS</b> Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS indicated that they would use this type of Automated Driving System.
S6:I would use this type of automated system.	Not Significant	Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS indicated that they would like this type of Automated Driving System in their current vehicle.
S7:I would like to have this type of automated system in my current vehicle.	Not Significant	Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS indicated that they would like this type of Automated Driving System in their future vehicle.
S8:I would like to have this type of automated system in my future vehicle.	Not Significant	Both drivers who received attention prompts from the DMS and drivers who did not receive attention prompts from the DMS indicated that they would like this type of Automated Driving System in their future vehicle.

Descriptive Statistics for responses to these questions and statements are displayed in

Table 4.

***Table 4. Summary of Descriptive Statistics for the After-Experience Satisfaction Ratings by Prompt Condition***

Satisfaction Statement	2-Seconds				7-Seconds				No prompts			
	$\mu$	S.D.	Min	Max	$\mu$	S.D.	Min	Max	$\mu$	S.D.	Min	Max
<b>S1</b>	5.6	1.4	3	7	6.0	1.1	2	7	6.6	0.6	5	7
<b>S2</b>	4.7	1.8	1	7	5.7	1.4	1	7	6.0	1.0	4	7
<b>S3</b>	5.3	1.4	2	7	5.9	0.9	3	7	6.1	0.9	3	7
<b>S4</b>	5.8	1.1	3	7	6.2	0.9	4	7	6.1	0.9	3	7
<b>S5</b>	5.4	1.3	1	7	5.6	1.3	1	7	6.1	0.9	4	7
<b>S6</b>	5.2	1.6	2	7	5.5	1.5	1	7	6.2	1.3	2	7
<b>S7</b>	5.3	1.7	2	7	5.4	1.8	1	7	6.4	1.0	3	7
<b>S8</b>	6.1	1.2	2	7	6.1	1.4	1	7	6.5	1.0	3	7

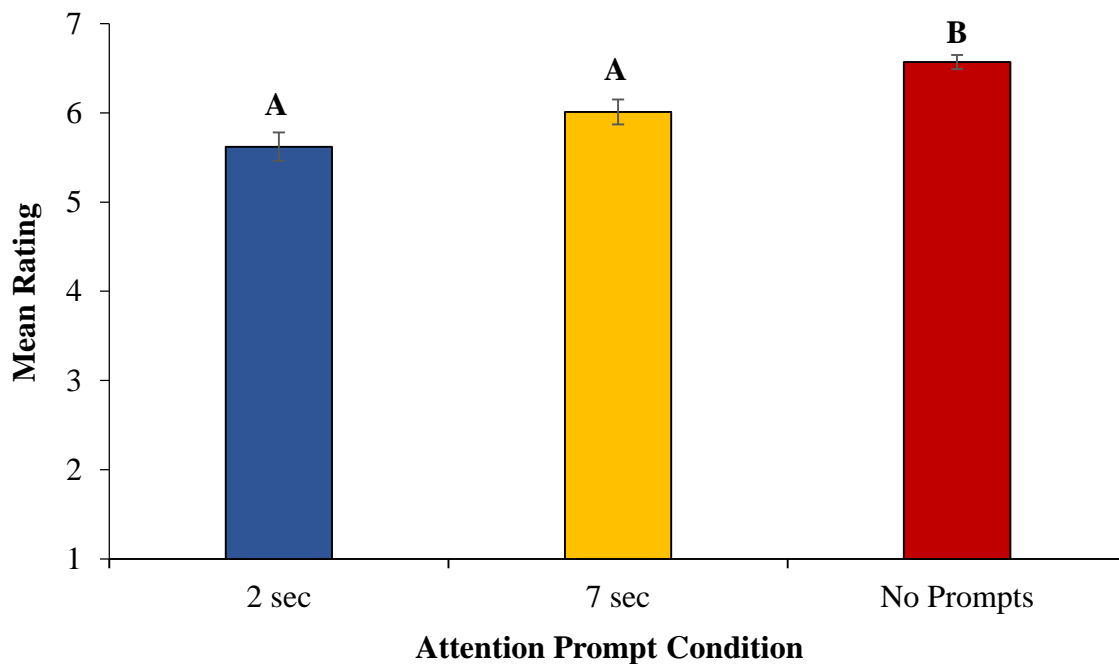
Cronbach's alpha was 0.86 meaning that there was good internal consistency among the satisfaction questions and statements. Correlations between the satisfaction questions and statements can be found in Appendix C.

### ***3.2.2 Analysis of After-Experience Satisfaction Ratings***

The Kruskal-Wallis test was conducted to determine whether driver satisfaction ratings varied as a function of attention prompt condition. Driver satisfaction ratings varied as a function of attention prompt condition on three of the satisfaction questions/statements: 1) "How satisfied were you with the automated system?" 2) "How satisfied were you with the number of alerts provided?" and 3) "The automated system's alerts provided sufficient information to make a decision."

*“How satisfied were you with the automated system?”*

Results from the Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2(2) = 23.62, p < 0.001$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS were less satisfied with the Automated Driving System than drivers who did not receive attention prompts from the DMS (see Figure 7 shown below).

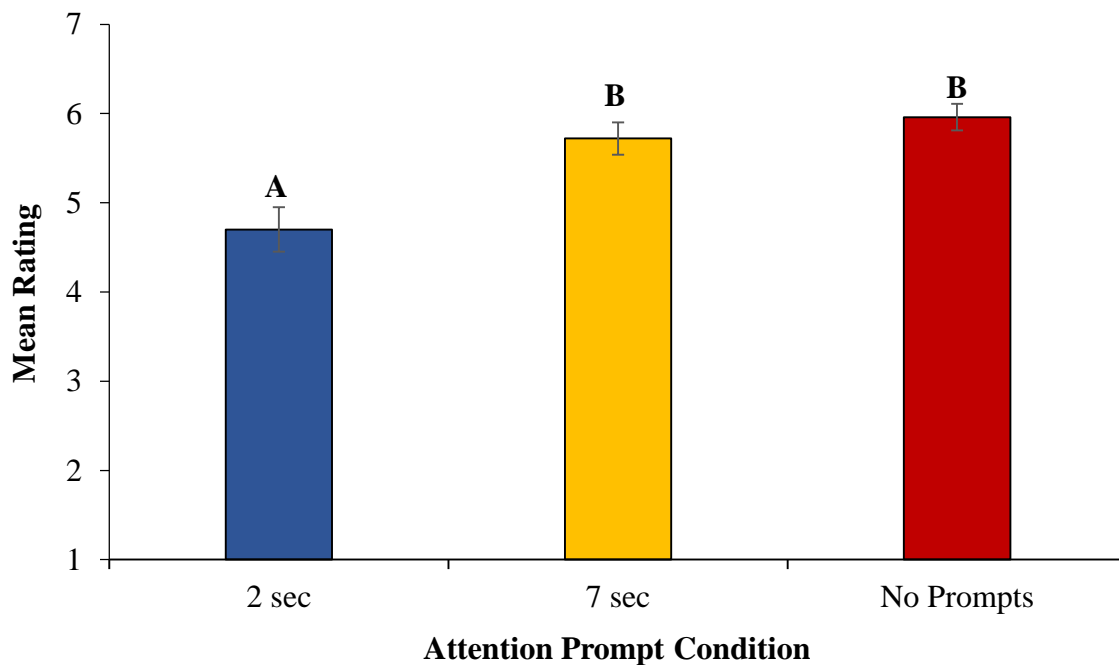


***Figure 7. Mean and Standard Error Bar Plot for After Experience Satisfaction Question “How Satisfied Were You with the Automated System,” from 1 Extremely Dissatisfied to 7 Extremely Satisfied. Different Letters Represent a Statistically Significant Difference.***

Specifically, drivers who received attention prompts after 2-seconds of inattention had significantly lower satisfaction ratings compared to drivers who did not receive attention prompts from the DMS ( $Z = 4.77, p < 0.0001$ ). Similarly, drivers who received attention prompts after 7-seconds of inattention had significantly lower satisfaction ratings compared to drivers who did not receive attention prompts from the DMS ( $Z = 3.00, p = 0.0076$ ).

*“How satisfied were you with the number of alerts provided?”*

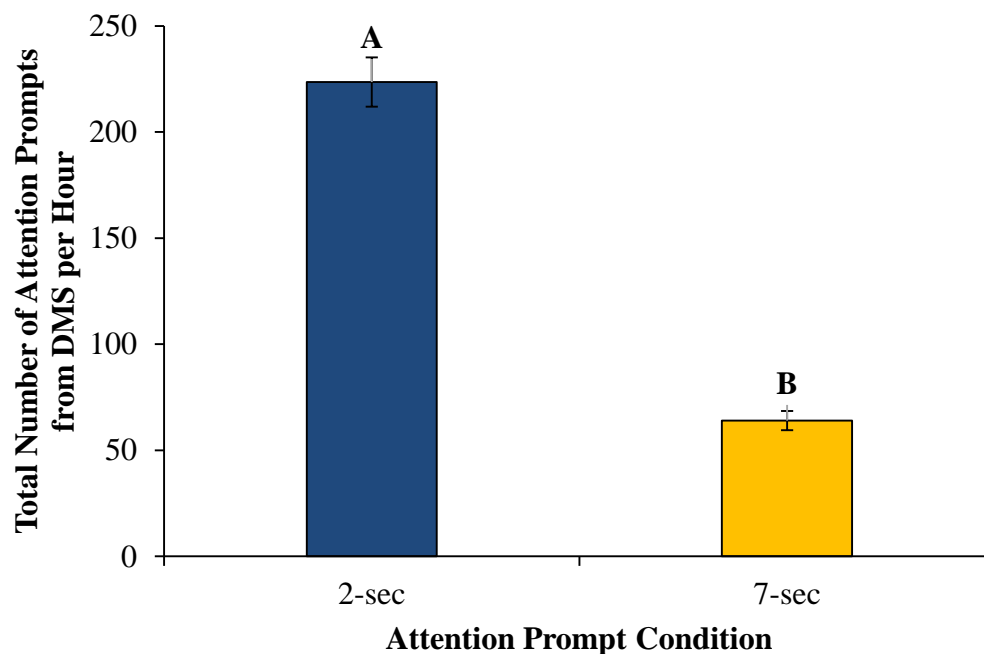
Results from the Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2(2) = 16.14, p = 0.0003$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS after 2-seconds of inattention lower satisfaction with the number of alerts provided, compared to drivers who received attention prompts from the driver monitoring system after 7-seconds of inattention and drivers who did not receive attention prompts from the DMS (see Figure 8 shown below).



***Figure 8. Mean and Standard Error Bar Plot for After Experience Satisfaction Question “How Satisfied Were You with the Number of Alerts Provided,” from 1 Extremely Dissatisfied to 7 Extremely Satisfied. Different Letters Represent a Statistically Significant Difference.***

Specifically, drivers who received attention prompts after 2-seconds of inattention had significantly lower ratings on this satisfaction question compared to drivers who did not receive attention prompts from the DMS ( $Z = 3.68, p = 0.0007$ ) and drivers who received attention prompts from the DMS after 7-seconds of inattention ( $Z = 3.26, p = 0.0032$ ).

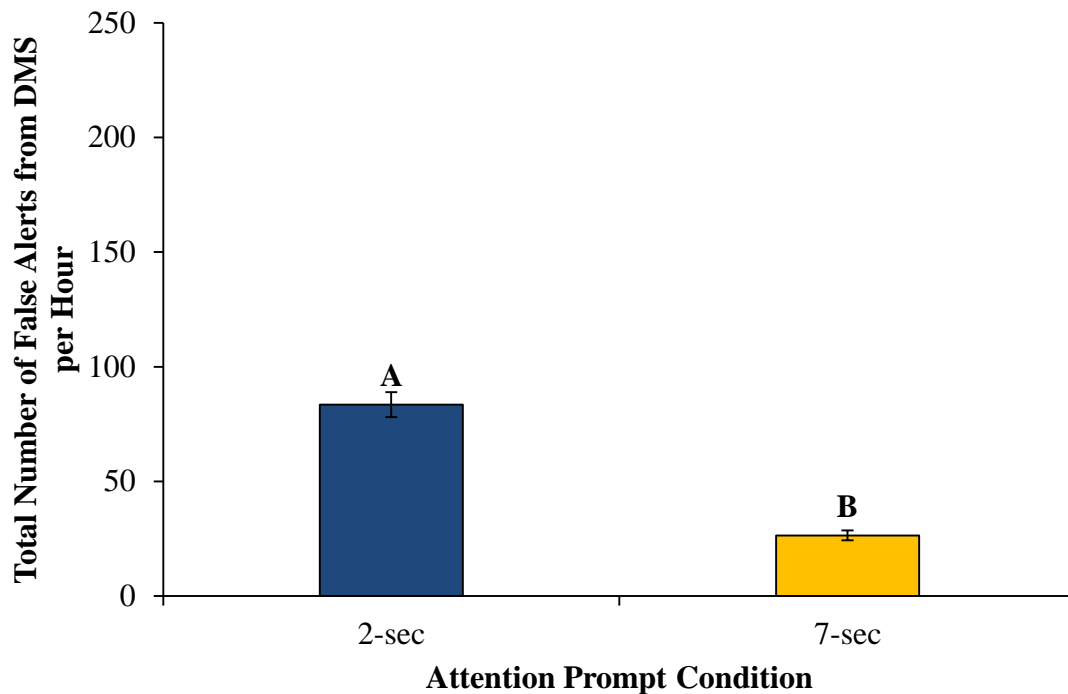
Results from the Wilcoxon Test revealed that drivers who received prompts from the DMS after 2-seconds of inattention experienced significantly more alerts from the driver monitoring system compared to drivers who received prompts from the DMS after 7-seconds of inattention ( $Z = 8.60, p < 0.0001$ ). Drivers in the 7-second attention prompt condition were allowed to detach from monitoring the driving environment over 3 times longer than drivers in the 2-second attention prompt condition. As such, drivers in the 2-second attention prompt condition received more attention prompts than drivers in the 7-second attention prompt condition. Specifically, drivers in the 2-second attention prompt condition on average received 3 times the number of attention prompts as drivers in the 7-second attention prompt condition (See Figure 9)



**Figure 9. Mean and Standard Error Bar Plots of the Number of Alerts Issued by the Driver Monitoring System by Attention Prompt Condition. Different Letters Represent a Statistically Significant Difference.**

Results from the Wilcoxon Test revealed that drivers who received attention prompts from the DMS after 2-seconds of inattention experienced significantly more false alerts from the

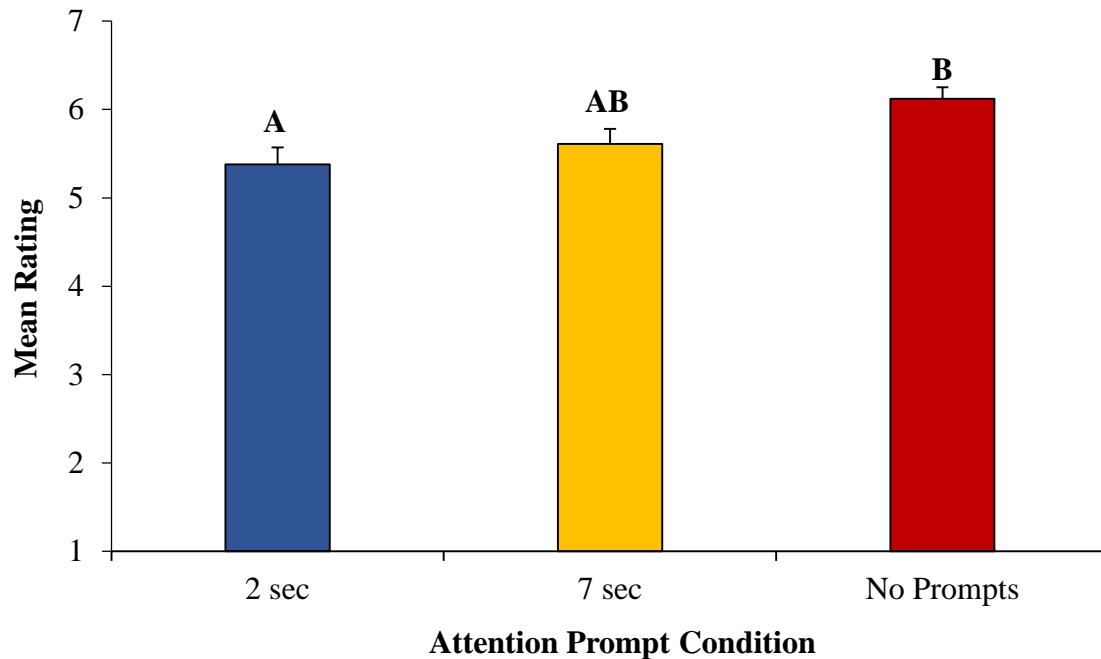
driver monitoring system compared to drivers who received attention prompts from the DMS after 7-seconds of inattention ( $Z = 7.49, p < 0.001$ ). Drivers in the 2-second attention prompt condition experienced on average 3 times the number of false alerts from the DMS as drivers in the 7-second prompt condition (See Figure 10.)



**Figure 10. Mean and Standard Error Bar Plots of the Number of False Alerts Issued by the Driver Monitoring System by Attention Prompt Condition. Different Letters Represent a Statistically Significant Difference.**

*“The automated system’s alerts provided sufficient information to make a decision.”*

Results from the Kruskal-Wallis test indicated that drivers’ ratings on this statement varied as a function of attention prompt condition ( $\chi^2 (2) = 9.31, p = 0.0095$ ). The post hoc Steel-Dwass test indicated that drivers who received attention prompts from the DMS after 2-seconds of inattention were less satisfied with the amount of information provided by the alerts compared to drivers who did not receive attention prompts from the DMS (see Figure 11 shown below).



***Figure 11. Mean and Standard Error Bar Plot for After Experience Satisfaction Statement “The Automated System’s Alerts Provided Sufficient Information to Make a Decision,” from 1 Strongly Disagree to 7 Strongly Agree. Different Letters Represent a Statistically Significant Difference.***

Specifically, drivers who received attention prompts after 2-seconds of inattention had significantly lower ratings on this satisfaction statement compared to drivers who did not receive attention prompts from the DMS ( $Z = 2.94, p = 0.0093$ ).



### 3.3 Performance during Lane Drift with No Alert

#### 3.3.1 Overview of Performance during Lane Drift with No Alert and Results

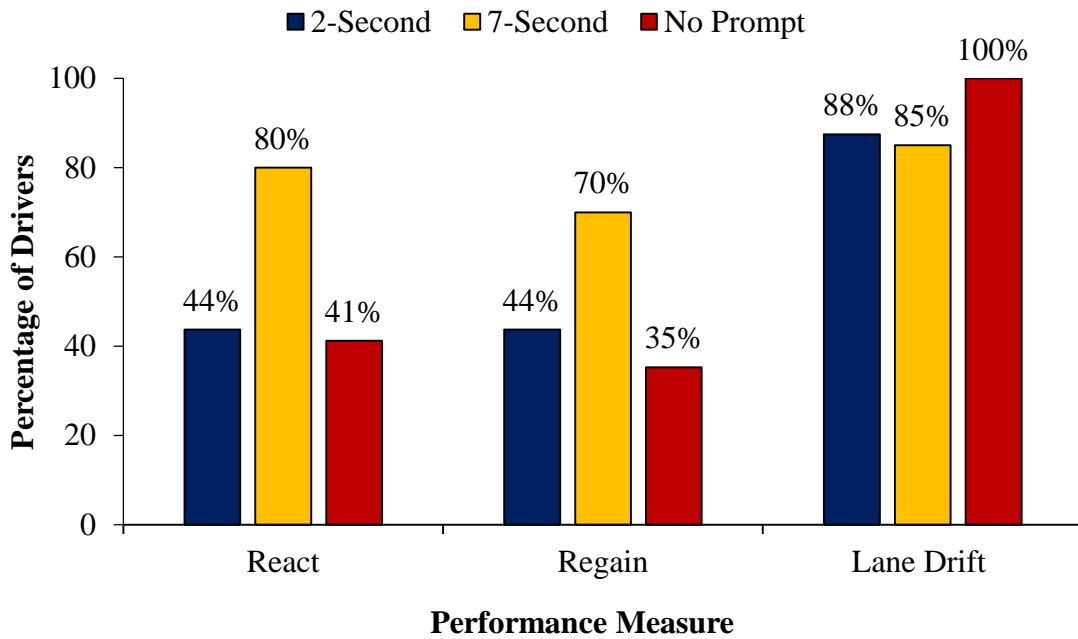
Table 5 below depicts a summary of the results for driver performance during the lane drift with no alert. Only significant results from this table are reported in the analysis section.

*Table 5. Summary Table for Performance Analysis during the Lane Drift with No Alert*

Performance Measure	Attention Prompt Condition	Take Away
React	Significant	<b>Drivers in the 7-second attention prompt condition were more likely to react during the lane drift with no alert compared to drivers who did not receive attention prompts.</b>
Regain	Not significant	Attention prompt condition did not significantly affect whether drivers regained control during the lane drift with no alert. However, a higher percentage of drivers in the 7-second attention prompt condition regained control compared to drivers in the 2-second attention prompt condition and drivers who did not receive attention prompts.
Lane Excursion	Not significant	Attention prompt condition did not affect where drivers experienced a lane excursion during the lane drift with no alert. A high percentage of drivers across all three attention prompt condition experienced a lane excursion.

Eighty percent of drivers who received attention prompts after 7-seconds of inattention reacted to the lane drift with no alert, compared to 44% of drivers who received attention prompts after 2-seconds of inattention and 41% of drivers who did not receive attention prompts at all. Seventy percent of drivers who received attention prompts after 7-seconds regained control of the steering wheel during the lane drift with no alert, compared to 44% of drivers who

received attention prompts after 2-seconds of inattention and 35% of drivers who did not receive attention prompts at all. Eighty-five percent of drivers who received attention prompts after 7-seconds of inattention drifted from the lane, compared to 88% of drivers who received attention prompts after 2-seconds of inattention and 100% of drivers who did not receive attention prompts at all.



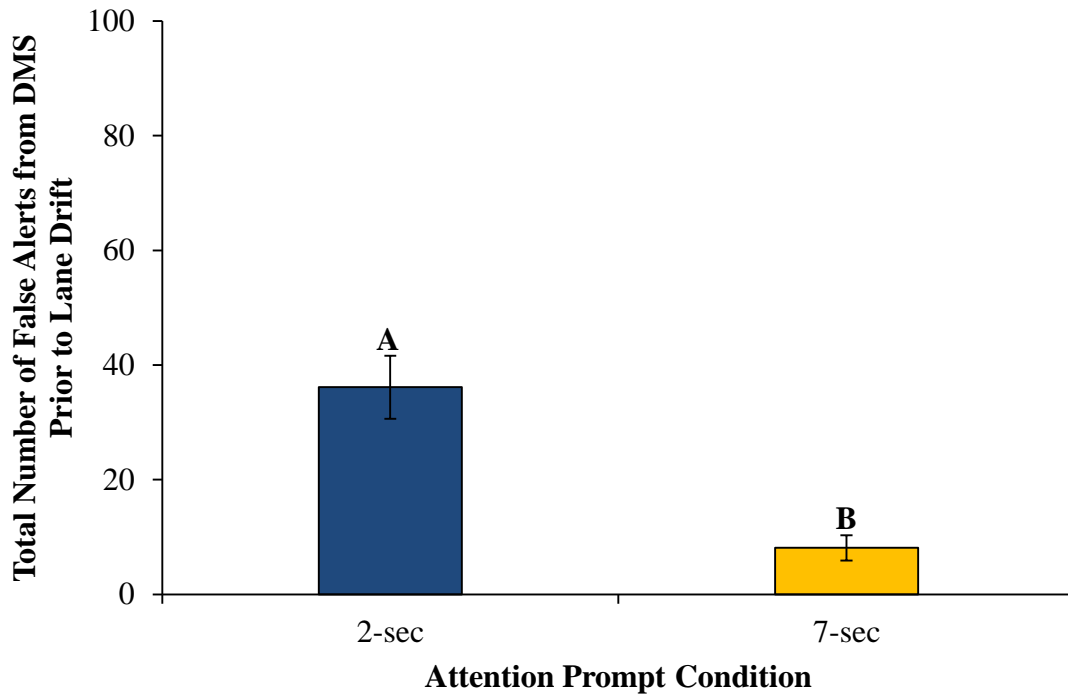
**Figure 12. Percentage of Drivers who Reacted, Regained Control, and Experienced a Lane Excursion during the Lane Drift with No Alert by Attention Prompt Condition.**

### 3.3.2 Analysis of Performance during Lane Drift with No Alert

A logistic regression was used to predict whether drivers react to a lane drift with no alert, using attention prompt condition as the predictor. The results indicated that attention prompt condition can reliably distinguish between drivers who react and drivers who do not react during the lane drift with no alert ( $\chi^2(2) = 6.19, p = 0.0452$ ). The full model can be expressed as the following:  $\log \frac{p}{1-p} = -0.36 + 0.61(P2) + 1.74(P7)$ . This equation models the probability of reacting during the lane drift with no alert. Inputs for P2 (i.e., 2-second attention

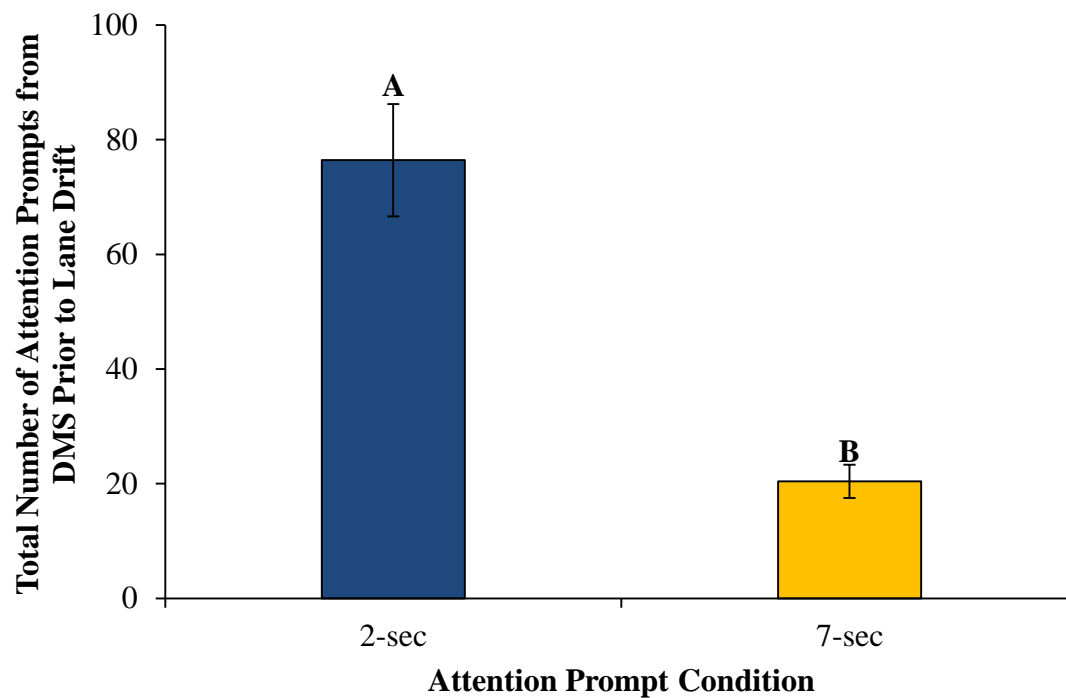
prompt condition) and P7 (i.e., 7-second attention prompt condition) were either 0 or 1, which represented not reacting and reacting respectively. Note that the intercept represents the logarithmic odds of reacting for drivers who do not receive attention prompts. The second parameter is the difference in the logarithmic odds for reacting between drivers in the 2-second attention prompt condition and drivers who did not receive attention prompts. Similarly, the third parameter is the difference in the logarithmic odds for reacting between drivers in the 7-second attention prompt condition and drivers who did not receive attention prompts. Odds ratios indicated that drivers in the 7-second attention prompt condition were 5.71 times more likely to react to the lane drift with no alert compared to drivers who did not receive attention prompts CI [1.33, 24.62].

Results from the Wilcoxon test revealed that drivers in the 7-second attention prompt condition received significantly less false alerts from the DMS prior to the lane drift compared to drivers in the 2-second attention prompt condition ( $Z = 4.11$ ;  $p < 0.0001$ ). Prior to the lane drift with no alert, drivers in the 2-second attention prompt condition experienced an average of 36 false alerts from the DMS while drivers in the 7-second attention prompt condition experienced an average of 8 false alerts from the DMS (see Figure 13).



***Figure 13. Mean and Standard Error Bar Plots of the Number of False Alerts Issued by the DMS prior to the Lane Drift with No Alert by Attention Prompt Condition. Different Letters Represent a Statistically Significant Difference.***

Results from the Wilcoxon test revealed that drivers in the 7-second attention prompt condition received significantly less attention prompts from the DMS prior to the lane drift with no alert compared to drivers in the 2-second attention prompt condition ( $Z = 4.20$ ;  $p < 0.0001$ ). Prior to the lane drift with no alert, drivers in the 2-second attention prompt condition experienced an average of 76 attention prompts from the DMS while drivers in the 7-second attention prompt condition experienced an average of 20 attention prompts from the DMS (see Figure 14).



***Figure 14. Mean and Standard Error Bar Plots of the Total Number of Prompts Issued by the DMS prior to the Lane Drift with No Alert by Attention Prompt Condition. Different Letters Represent a Statistically Significant Difference.***

## **CHAPTER 4: DISCUSSION**

### **4.1 Overview**

Level 2 Automated Driving Systems are becoming increasingly available features within the modern automobile. These systems are intended to alleviate and/or augment driver maintenance of longitudinal and lateral vehicle control (SAE J3016). With a Level 2 Automated Driving System, the role of the driver is transformed from active vehicle control to supervisory control (Trimble et al., 2014). In this regard, SAE (J3016) outlines the role of the driver when automation is activated. Drivers are still expected to monitor the driving environment and be available to take control of the vehicle with limited notice (SAE J3016); otherwise known as a vigilance task. However, humans perform poorly in regards to vigilance (Fitts, 1967). As such, researchers have begun developing DMSs. Ultimately these systems may help the driver monitor the driving environment at an appropriate level and maintain an adequate level of situation awareness. Current and existing research on how DMSs affect driver performance is limited. This thesis was aimed at addressing how a DMS affects drivers' experiences and interactions with an Automated Driving System.

Our first research question was centered on how a DMS affects drivers' trust and satisfaction with an Automated Driving System. Our second research question was centered on how a DMS affects drivers' ability to detect changes in the driving environment that require intervention (i.e., Level 1 situation awareness), which was represented by the experimenter triggered lane drifts.

## **4.2 Does a DMS Affect Drivers' Trust in the Automated Driving System?**

It was anticipated that drivers who received attention prompts from the DMS would report lower levels of trust in the Automated Driving System compared to drivers who did not receive attention prompts from the DMS. Specifically, it was hypothesized that driver trust in the Automated Driving System would decrease as the number of false alerts from the DMS increased. The results support this hypothesis as on three of the trust statements, drivers who received attention prompts from the DMS (and as such received false alerts from the DMS) had lower ratings compared to drivers who did not receive attention prompts from the DMS.

Specifically the after-experience trust ratings analysis revealed that drivers who received attention prompts from the DMS had lower trust ratings compared to drivers who did not receive prompts on three trust statements: 1) T1: "I can rely on the automated system," 2) T3: "The automated system gave false alerts," and 3) T6: "I trust the automated system." These three statements related to drivers' perceived reliability of the Automated Driving System, their perception of false alerts, and overall trust in the Automated Driving System. No difference was observed between drivers who received prompts after 2 seconds of inattention and drivers who received prompts after 7 seconds of inattention.

These results correspond with those obtained during previous research on driver trust and ADASs. Specifically, prior research suggests that the presence of false alarms results in a decrease in driver trust with ADASs (Abe, Ioth, & Tanaka, 2002; Abe & Richardson, 2005; Donmez, Boyle, Lee, & McGehee, 2006). In contrast to drivers who did not receive attention prompts from the DMS, drivers who received attention prompts from the DMS after 2-seconds of inattention were exposed to on average 223 attention prompts per hour and drivers who received attention prompts from the DMS after 7-seconds of inattention were exposed to on

average 64 attention prompts per hour. This equates to approximately 4 alerts per minute for drivers in the 2-second attention prompt condition and 1 alert per minute for drivers in the 7-second attention prompt condition. Of these alerts, approximately 44% were false alerts meaning that drivers received attention prompts from the DMS while they were attentive to the driving environment. Despite the high number of attention prompts and false alerts from the DMS, drivers in the 2-second and 7-second attention prompt conditions reported high levels of trust in the Automated Driving System.

However, drivers in the 2- and 7- second attention prompt conditions indicated that the Automated Driving System gave more false alerts (T3) compared to drivers who did not receive attention prompts. This was expected, considering that of the total alerts from the prototype DMS, approximately 44% were false alerts. While drivers who received false alerts from the DMS reported a lower level of trust in the reliability of the Automated Driving System while performing non-driving tasks (T1), and overall trust in the Automated Driving System (T6) it is important to note that these drivers still reported high levels of trust in the Automated Driving System.

In summary, the DMS attention prompt condition affected trust. Specifically, drivers who received attention prompts from the DMS reported lower levels of trust with the Automated Driving System compared to drivers who did not receive attention prompts. This may have been reflective of the number of false alerts drivers in the 2-second and 7-second attention prompt condition received from the DMS. However, it should be noted that across all attention prompt conditions, mean trust ratings were found to be “high” relative to the 7-point evaluation metrics used. Accordingly, the reported differences in trust were small, and therefore, may not be of practical significance in regard to future implementation.



### **4.3 Does a DMS Affect Drivers' Satisfaction with the Automated Driving System?**

It was anticipated that drivers who received attention prompts from the DMS would report lower levels of satisfaction with the Automated Driving System compared to drivers who did not receive attention prompts from the DMS. Specifically, it was hypothesized that as the number of false alerts from the DMS increased, satisfaction would decrease. This hypothesis was supported as results from the after-experience satisfaction ratings revealed that drivers who received attention prompts from the DMS had lower satisfaction ratings compared to drivers who did not receive attention prompts. Drivers who received attention prompts reported lower ratings on three satisfaction questions/statements: 1) S1: "How satisfied were you with the automated system?" 2) S2: "How satisfied were you with the number of alerts provided by the automated system?" and 3) S5: "The automated systems alerts provided enough information to make a decision."

It is not surprising that drivers in the 2-second attention prompt condition reported lower levels of satisfaction with the frequency (S2) of attention prompts relative to drivers in the 7-second and no attention prompt conditions. Drivers in the 2-second attention prompt condition received approximately 3 times the number of attention prompts compared to drivers in the 7-second attention prompt condition. As such it is likely that drivers in the 2-second attention prompt condition found the frequency at which they received attention prompts from the DMS to be annoying and unacceptable. In turn, this could have resulted in lower satisfaction ratings with the number of alerts. For example, one driver who received attention prompts after 2-seconds of inattention stated during the after-experience interview, "I was just annoyed by the number of alerts. It seems like it would provide an alert and I would look up and nothing was happening"

(Male; 26 years of age). Specifically, this driver expressed that the visual alerts were annoying and he indicated that either an auditory alert or haptic alert would be more effective.

Drivers who received attention prompts from the DMS were less satisfied with the Automated Driving System (S1) and drivers who received attention prompts from the DMS after 2-seconds of inattention were less satisfied with the information provided by the alerts (S5) compared to drivers who did not receive attention prompts.

In summary, the DMS attention prompt condition affected driver satisfaction with the Automated Driving System. Specifically, drivers who received attention prompts from the DMS reported lower levels of satisfaction with the Automated Driving System compared to drivers who did not receive attention prompts. This may have been reflective the frequency of attention prompts and the number of false alerts drivers in the 2-second and 7-second attention prompt condition received from the DMS. However, it should be noted that across all attention prompt conditions, mean satisfaction ratings were found to be “high” relative to the 7-point evaluation metrics used. Accordingly, the reported differences in trust were small, and therefore, may not be of practical significance in regard to future implementation. This suggests that OEMs can implement DMSs with their Automated Driving Systems and drivers will generally like the Automated Driving System, as long as they consider the frequency at which the DMS provides attention prompts. Future research should look to optimize the frequency of attention prompts from a DMS.

#### **4.4 Does a DMS Affect Drivers' Abilities to Detect Changes in the Driving Environment That Require Driver Intervention?**

It was hypothesized that drivers who received attention prompts from the DMS would be more likely to detect changes in the driving environment that required driver intervention compared to drivers who did not receive attention from the DMS. To test this hypothesis, driver performance during the lane drift with no alert was analyzed. The results from this analysis provide support for this hypothesis. Specifically, results demonstrated that drivers who received attention prompts after 7-seconds of inattention were over 5 times more likely to react (i.e., look forward) during the lane drift with no alert compared to drivers who did not receive attention prompts. As such, a higher percentage of drivers in the 7-second attention prompt condition were able to successfully regain control of the vehicle compared to drivers in the 2-second and no attention prompt conditions.

These results illustrate that a DMS may help a driver monitor the driving environment and ultimately detect changes in the driving environment that require intervention. A higher proportion of drivers who received prompts after 7-seconds of inattention from the DMS reacted and regained control during a lane drift with no alert. Drivers who did not receive any alerts from the DMS exhibited the worst performance. This corresponds with results from previous research, which suggest that Automated Driving Systems may have deleterious effects on a driver's situation awareness and performance during take-over requests (Merat, Jamson, Lai, Daly, & Carsten, 2014; Gold, Dambock, Lorenz, & Bengler, 2013). Ultimately this indicates that without a DMS drivers may fail to monitor the driving environment at an appropriate level and as a result may miss events in the driving environment that require driving intervention. While this has yet

to be confirmed using a real-world driving setting, it highlights the need for OEMs to design Level 2 Automated Driving Systems that aid the driver in monitoring the driving environment.

Of interest is the performance of drivers in the 2-second attention prompt condition compared to drivers in the 7-second prompt condition. Seventy percent of drivers in the 7-second prompt condition group regained control during the lane drift with no alert compared to 44% of drivers in the 2-second attention prompt condition (see pg. 34 Figure 12). Prior to the lane drift with no alert, drivers in the 2-second attention prompt condition received three times the number of attention prompts compared to drivers in the 7-second attention prompt condition.

It is possible that the frequency in which drivers received attention prompts in the 2-second prompt condition resulted in drivers over-relying on the DMS to guide their monitoring behavior. Conversely, it is possible that drivers in the 2-second attention prompt condition began to habituate to the DMS. Blanco et al., (2015) noted that early in the study, drivers responded (i.e., looked forward) to the Stage 1 attention prompts; however, over time some drivers habituated to the Stage 1 attention prompts and would only respond to the Stage 2 and Stage 3 attention prompts. Some drivers would even ignore the Stage 3 attention prompts to complete the non-driving task. In either case, when the vehicle began to drift from the lane, some drivers did not react (i.e., look forward) because they were relying too heavily on the Automated Driving System to function properly. For example, one driver noted, “My immediate and main concern would be the overconfidence, and over-relying on the device in a common public environment, where people are too comfortable, and rely on it too heavily. I purposefully allowed myself to do this and found it to be a dangerous and questionable activity. I would like to see alerts, or subtle consistent notifications about my vehicle position that are not visual based,” (Male; 24 years of age). While the difference between drivers in the 2-second and 7-second prompt conditions were

not statistically significant, it suggests that the time interval used for the onset of the attention prompts needs to be considered.

In summary, these results suggest that DMSs can enhance a driver's ability to detect changes in the driving environment that require intervention. However, it is important to take the DMS attention prompt onset time interval into consideration in order to enhance driver performance. The results indicated that drivers in the 7-second attention prompt condition were more likely to react during the lane drift with no alert compared to drivers who did not receive attention prompts. Moreover, a higher percentage of drivers in the 7-second attention prompt condition were able to regain control of the vehicle than drivers in the 2-second attention prompt condition. NHTSA's Visual-Manual Distraction Guidelines (2013) indicate that OEMs should design systems and displays to ensure that drivers do not take their eyes off the road for longer than 2-seconds due to the increased risk for experiencing a crash during off-road glances that exceed 2-seconds. However, in the context of an Automated Driving System drivers may habituate to attention prompts that are triggered after 2-seconds of inattention. As such, a DMS may be more effective at enhancing driver performance if drivers are allowed to detach from monitoring the driving environment for longer than 2-seconds. Future research is needed in order to ensure a balance between safety and convenience for the driver.

#### **4.5 Design Implications**

There are several key findings from this study that can serve to inform researchers and OEMs designing Automated Driving Systems.

#### ***4.5.1 OEMs Can Incorporate DMSs and Drivers Will Trust and Be Satisfied with the Automated Driving System.***

On average, 44% of attention prompts drivers received from the prototype DMS were false alerts. As such, drivers in the 2-second and 7-second attention prompt conditions reported slightly lower trust and satisfaction with the Automated Driving System compared to drivers who did not receive attention prompts. While drivers' trust and satisfaction with the Automated Driving System was affected by the DMS, drivers who received attention prompts still reported "high" levels of trust and satisfaction relative to the 7-point evaluation metrics. This suggests that OEMs can incorporate DMSs to help the driver monitor the driving environment and drivers will still trust and be satisfied with the Automated Driving System. Moreover, this may suggest that the OEMs can create "conservative" DMSs meaning that the DMS can err on the side of safety and issue attention prompts during instances where it is uncertain whether or not the driver is attentive or inattentive.

#### ***4.5.2 OEMs Should Consider the Frequency of Attention Prompts***

Drivers in the 2-second attention prompt condition received three times the number of attention prompts and false alerts from the DMS relative to drivers in the 7-second attention prompt condition. As such, drivers in the 2-second attention prompt condition reported lower levels of satisfaction with the frequency of alerts compared to drivers in the 7-second and no prompt conditions. Moreover, attention prompt condition was found to affect driver performance. Specifically, a higher percentage of drivers in the 7-second attention prompt condition reacted and regained control of the vehicle during the lane drift with no alert compared to drivers in the 2-second and no prompt conditions.

It is possible that drivers in the 2-second prompt condition may have found the frequency of attention prompts from the DMS to be annoying. This may have led drivers in the 2-second attention prompt condition to ignore the attention prompts. Blanco et al., (2015) observed that initially drivers responded to the Stage 1 attention prompts; however, over time drivers began to ignore the Stage 1 attention prompts and respond to the Stage 2 or Stage 3 attention prompts. This suggests that OEMs need to consider the frequency at which drivers receive attention prompts from a DMS to enhance driver performance and avoid the occurrence of alert annoyance habituation. Ultimately, OEMs need to create a balance between safety and convenience for the driver. In regard to Level 2 Automated Driving Systems, the primary focus should be to ensure safety as these systems have their limitations and are not intended to be used to simulate a highly automated vehicle.

#### **4.6 Limitations and Opportunities for Future Research**

While this study was able to address how drivers' interactions and experiences with an Automated Driving System are affected by a DMS, there are some limitations. For instance, the DMS triggered attention prompts after 2 consecutive seconds of inattention and 7 consecutive seconds of inattention. Attention prompt trigger times between 2 and 7 seconds and greater than 7 seconds were not tested. It is possible that an attention prompt trigger time between 2 and 7 seconds or greater than 7 seconds may result in optimal driver trust, satisfaction, and performance. As previously discussed, the attention prompt condition affected driver trust, satisfaction, and performance with the Automated Driving System. Future research is needed to evaluate the effects of different attention prompt trigger times on driver trust, satisfaction, and performance with a Level 2 Automated Driving System. This will ensure that OEMs created Automated Driving Systems with DMSs that are safe and enjoyable to use.

A second key limitation stems from the use of a prototype Automated Driving System and a test track environment. This may limit the ecological validity of the results. A naturalistic driving study is needed to delineate how drivers interact with an Automated Driving System and DMS in a real-world setting. This would allow researchers to evaluate how drivers trust and satisfaction changes over a period of days, weeks, and months. The present study relied on two-in-vehicle experimenters. It is possible that the mere presence of the experimenters led drivers report high levels of trust in the Automated Driving System. One driver noted in the after-experience interview “the experimenter wouldn’t be interested in going in a vehicle that was not at least reasonably safe. So even just stepping in the door, I put a fair amount of trust in whatever I was going to drive today.” In the absence of the experimenter, drivers may exhibit lower levels of trust in the Automated Driving System and may require a longer exposure period to the Automated Driving System in order to achieve trust that is calibrated to the systems capabilities. Additionally, by using a naturalistic driving approach, researchers could explore how drivers respond to take-over requests and how this is affected by different DMS attention prompt trigger times. During this experiment, drivers performed visually intensive non-driving tasks at the command of the experimenter. This was intended to capture driver performance under distraction. The degree to which drivers engage in non-driving tasks while using an Automated Driving System in a real driving environment has yet to be explored.

Currently OEMs are not required to provide training on the operation of Level 2 Automated Driving Systems. This creates the rental car scenario where drivers operate an unfamiliar vehicle that may issue unfamiliar alerts. This study was designed to mimic this condition, and accordingly, the experimenter did not provide the driver with any explanation of the alerts issued by the DMS and did not instruct the driver how to respond to these alerts.



Drivers were expected to learn to transition attention to the driving environment when they received an alert from the DMS. During instances in which the DMS would issue false alerts (i.e., when the system would provide alerts to a driver that was attentive to the driving environment), drivers may have developed their own unique mental model for why they were receiving alerts. Additionally, it is possible that drivers were unable to differentiate false alerts from true alerts, because they were not provided with an explanation for what triggered the alerts. However, in a naturalistic driving setting, drivers may be unable to differentiate between false alerts and true alerts; therefore, the results from this study may be an accurate representation of how drivers would perceive attention prompts in a naturalistic driving environment.

## **4.7 Conclusion**

Drivers' trust, satisfaction, and performance with an Automated Driving System was affected by the DMS. While drivers who received attention prompts from the DMS had lower trust and satisfaction ratings on some of the survey items, drivers generally had "high" levels of trust across the three prompt conditions. This suggests that OEMs can implement DMS that drivers deem trustworthy and satisfactory.

With regards to driver performance during the lane drift with no alert, drivers in the 7-second attention prompt condition exhibited the best performance compared to drivers in the 2-second and no prompt conditions. This highlights the need for OEMs to consider the attention prompt trigger time in order to achieve a balance between safety and convenience for the driver.

Ultimately these results may aid OEMs designing Automated Driving Systems to help ensure that drivers are able to safely interact with these systems. The Society of Automotive Engineers outlines the role of the driver under different levels of automation (SAE J3016). With

current vehicles (i.e., Level 2; Partial Automation), drivers are expected to constantly monitor the driving environment and are responsible for resuming control of the vehicle at any point under limited notice. While humans generally perform poorly at prolonged monitoring tasks, OEMS can incorporate DMS with their Automated Driving Systems to aid the driver with monitoring the driving environment. The results from our study suggest that incorporating a DMS can be achieved without severely hindering driver trust and satisfaction with the vehicle. However, the timing of the DMS alerts needs to be considered in order to achieve optimal driver performance. Essentially OEMS can incorporate a DMS to enhance drivers' performance. Ultimately, this contributes to the development of Automated Driving Systems that are safe and convenient to use, which may help ensure that the promised safety benefits of Automated Driving Systems are fully realized.

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## APPENDICES

### Appendix A: After-Experience Trust Survey

Participant Number:

Circle the number that best describes your feeling or impression.

1.) I can rely on the automated system to function properly while I am doing something else.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

2.) The automated system provided the alerts when needed.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

3.) The automated system gave false alerts.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

4.) The automated system is dependable.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

5.) I am familiar with the automated system.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

6.) I trust the automated system.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

## Appendix B: After-Experience Satisfaction Survey

**Participant Number:**

**Mark an “x” on each line at the point which best describes your feeling or impression.**

1.) Overall, how satisfied are you with the automated system?

1	2	3	4	5	6	7
Extremely Dissatisfied	Moderately Dissatisfied	Slightly Dissatisfied	Neither Dissatisfied Nor Satisfied	Slightly Satisfied	Moderately Satisfied	Extremely Satisfied

2.) How satisfied were you with the number of alerts provided?

1	2	3	4	5	6	7
Extremely Dissatisfied	Moderately Dissatisfied	Slightly Dissatisfied	Neither Dissatisfied Nor Satisfied	Slightly Satisfied	Moderately Satisfied	Extremely Satisfied

3.) How satisfied were you with the types of alerts provided?

1	2	3	4	5	6	7
Extremely Dissatisfied	Moderately Dissatisfied	Slightly Dissatisfied	Neither Dissatisfied Nor Satisfied	Slightly Satisfied	Moderately Satisfied	Extremely Satisfied

4.) The automated system's alerts provided sufficient time to make a decision.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

5.) The automated system's alerts provided sufficient information to make a decision.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

6.) I would use this type of automated system during my normal driving.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

7.) I would like to have this type of automated system as part of my current vehicle.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree



8.) I would like to have this type of automated system as part of a future vehicle.

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	Neither Agree Nor Disagree	Slightly Agree	Moderately Agree	Strongly Agree

## Appendix C: Item Analysis for Trust and Satisfaction Scales

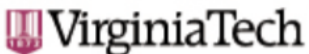
*Table 6. Inter-Item Correlation Matrix for Trust Scale Statements*

	<b>T1</b>	<b>T2</b>	<b>T3</b>	<b>T4</b>	<b>T5</b>	<b>T6</b>
<b>T1</b>	1.000	.474	.201	.815	.463	.826
<b>T2</b>	.474	1.000	.331	.454	.294	.434
<b>T3</b>	.201	.331	1.000	.208	.042	.205
<b>T4</b>	.815	.454	.208	1.000	.485	.809
<b>T5</b>	.463	.294	.042	.485	1.000	.551
<b>T6</b>	.826	.434	.205	.809	.551	1.000

*Table 7. Inter-Item Correlation Matric for Satisfaction Scale Statements/Questions*

	<b>S1</b>	<b>S2</b>	<b>S3</b>	<b>S4</b>	<b>S5</b>	<b>S6</b>	<b>S7</b>	<b>S8</b>
<b>S1</b>	1.000	.486	.392	.464	.490	.378	.303	.245
<b>S2</b>	.486	1.000	.676	.434	.596	.367	.335	.285
<b>S3</b>	.392	.676	1.000	.384	.280	.247	.282	.222
<b>S4</b>	.464	.434	.384	1.000	.558	.331	.303	.194
<b>S5</b>	.490	.596	.280	.558	1.000	.521	.479	.380
<b>S6</b>	.378	.367	.247	.331	.521	1.000	.805	.804
<b>S7</b>	.303	.335	.282	.303	.479	.805	1.000	.801
<b>S8</b>	.245	.285	.222	.194	.380	.804	.801	1.000

## Appendix D: IRB Approval Letter



Office of Research Compliance  
Institutional Review Board  
North End Center, Suite 4120, Virginia Tech  
300 Turner Street NW  
Blacksburg, Virginia 24061  
540/231-4606 Fax 540/231-0959  
email [irb@vt.edu](mailto:irb@vt.edu)  
website <http://www.irb.vt.edu>

### MEMORANDUM

**DATE:** July 21, 2015  
**TO:** Myra Blanco, Holly Vasquez, Joseph L Gabbard Jr, Nathan Ka Ching Lau, Jonathan Richard Atwood  
**FROM:** Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)  
**PROTOCOL TITLE:** Evaluation of System Reliability on Driver Trust, Satisfaction, and Performance with a Level 2 Automated Driving System  
**IRB NUMBER:** 15-695

Effective July 21, 2015, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<http://www.irb.vt.edu/pages/responsibilities.htm>

(Please review responsibilities before the commencement of your research.)

### PROTOCOL INFORMATION:

Approved As: Expedited, under 45 CFR 46.110 category(ies) 5  
Protocol Approval Date: July 21, 2015  
Protocol Expiration Date: July 20, 2016  
Continuing Review Due Date\*: July 6, 2016

\*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

### FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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