5-2016

Quantifying Drivers' Responses to Failures of Semi-autonomous Vehicle Systems

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QUANTIFYING DRIVERS' RESPONSES TO FAILURES OF SEMI-AUTONOMOUS VEHICLE SYSTEMS

A Dissertation
Presented to
the Graduated School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Industrial Engineering

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by
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May 2016

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ABSTRACT

The number of vehicles on the road with advanced and automated driving support systems (DSSs) is increasing. However, there may be some issues related to the implementation of DSSs in vehicles. One of those issues caused by the automated DSSs relates to the drivers' being out-of-the-loop. As drivers' roles are transitioned from system operators to systems supervisors (as in autonomous vehicles), drivers' situation awareness of the driving surroundings may decrease which could negatively affect their responses when they need to take control of the vehicle from the malfunctioned (or failed) DSSs. Additionally, with both the adaptive cruise control (ACC) and lane keeping (LK) systems engaged, the longitudinal and lateral positions of the vehicle are under the control of automation and the vehicle becomes a semi-autonomous vehicle (i.e., the vehicles are now at level 2 automation based on the definitions of the National Highway Traffic Safety Administration taxonomy for automation). In semi-autonomous vehicles, drivers are more likely to interact with non-driving tasks and engage in risky behaviors (e.g., long glances away from the forward road way), as the demand of the driving tasks is much lower than manually driving and driving with only ACC engaged. This may worsen drivers' responses to the failures of semi-autonomous vehicle components, when drivers are engaged in non-driving tasks.

The objectives of this dissertation were to assess how drivers respond to the failures of the LK system with different levels of vehicle automation and to assess the effects of drivers' engagements in non-driving tasks on their behaviors associated with a failure of

the LK system. This dissertation also investigates if a lane departure warning would mitigate the negative effects of out-of-the-loop problem brought on by automation and improve drivers' responses to the LK system fails especially when drivers are engaging both the ACC and LK systems. Additionally, the relationships between drivers' personalities and attitudes toward automation and their responses during the failure of the LK system were evaluated.

Three experiments were used to address the dissertation research objectives. The results demonstrate that drivers in semi-autonomous vehicles (level 2 automation vehicles) have less safe behaviors (e.g., more engagement in non-driving tasks and longer glances away from the roadway) than their peers who were manually driving the vehicles. During the failures of the LK systems, drivers in semi-autonomous vehicles have worse driving behaviors compared to their counterparts driving manually or driving with the LK system engaged. Non-driving tasks also increase drivers' reaction time to safety critical events in semi-autonomous vehicles. However, the effects of audible lane departure warnings on drivers' responses to potential lane departure events were not consistent between the level 0 automation condition (i.e., the manual driving condition) and level 2 automation condition (i.e., the automated driving condition). Overall, audible warnings with 1.48 s prediction time assist drivers' in responding to the lane departure events following the failure of the LK system in semi-autonomous vehicles. However, the effects of audible warnings on drivers' responses to the potential lane departure events are divergent when drivers are manually operating the vehicles. Though audible warnings as one type of discrete feedback of automation activities help drivers improve their responses to safety critical events in semi-autonomous vehicles, they cannot solve the out-of-control loop problem caused by automation. Future work should evaluate if continuous feedback could address the out-of-control loop problem brought on by automation and keep drivers in the vehicle control loop in semi- or fully- autonomous vehicles.

To my parents: Yang Shen and Xiaoxu Shen

ACKNOWLEDGMENTS

Many people helped me in different ways during my Ph.D. study. First and foremost, I would like to express my deep appreciation to my advisor Dr. David Neyens, for his guidance, patience, and support during my four-year Ph.D. life. Dr. Neyens has not only provided me detailed guidance of my Ph.D. research, but also motivated me to be an excellent human factors researcher.

My sincere gratitude also goes to other members of my committee Dr. B. Rae Cho, Dr. William G. Ferrell, Dr. Mary Elizabeth Kurz-Edsall, and Dr. Sara Lu Riggs for their support, suggestions, and supervision that contributed to the improvement and completion of my dissertation.

I would like to thank my lab peers in the Ergonomics and Applied Statistics Lab (EAST) at the Department of Industrial Engineering of Clemson University, especially Myrtede Alfred, Mary (Ali) Hobbs, Elizabeth Jamison, and Katie Jurewicz, for providing me with valuable comments and feedback on my dissertation and helping me improve my English. I would also like to thank my friends, especially Yating Chai, Zhenyu Wang, Kun Dan, and Jing Chang, who encouraged me when I felt upset by my research.

Last, but not the least, I want to express my tremendous gratitude to my parents, albeit I understand any amount of gratitude shown to them is inadequate. I am deeply thankful for their unconditional mental and physical supports in my 28-years' life.

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CHAPTER 1: OVERVIEW

The number of vehicles on the road with advanced and automated driver support system (DSS) is increasing. There are several types of driver support systems (DSS) developed by vehicle manufacturers that are either currently available or that will be available in the near future, such as the adaptive cruise control (ACC) system, lane keeping (LK) system, and lane departure warning (LDW) system (Suzuki & Jansson, 2003; Vahidi & Eskandarian, 2003; Dagan et al., 2004). The purposes of implementing automated DSSs in vehicles are to reduce the risks of traffic crashes, enhance drivers' comfort and performance, and reduce the fuel consumption (Bishop, 2000; Vahidi & Eskandarian, 2003). Some of the DSSs (e.g., LDW and FCW systems) provide information and advice to help drivers avoid road hazards and unsafe driving behaviors and some of them (e.g., the ACC and the LK system) directly control the longitudinal and lateral positions of the vehicle. However, automated DSSs do not work well across all the situations. For example, as ACC is designed to improve drivers comfort, the braking power of is limited to between 0.2 to 0.3g (Nilsson, 1995; Xiong et al., 2012). If the leading vehicle brakes beyond the braking power of ACC, the driver must take over the vehicle and apply force to the brake pedal otherwise a collision may occur. Traditionally, ACC does not detect and reduce speed in responses to stationary objects and the headway control is only performed within a limited speed interval (Marsden, McDonald, & Brackstone, 2001). The misusage of automated systems and the failures of automated systems can lead to critical safety situation. For example, Stanton, Young, and McCaulder (1997) induced an unexpected acceleration into ACC system during regular driving conditions on a driving simulator, which led to a collision 33% of the time (four of the twelve participants failed to reclaim control of the vehicle efficiently).

The levels of automation within a system control can range from fully manually control, to automated decision support, and to fully automation control (Endsley & Kiris, 1995). With both the ACC and LK systems engaged, the longitudinal and lateral positions of the vehicle are under the control of those DSSs and the vehicle becomes a semi-autonomous vehicle (a level 2 automation vehicle). Some studies have shown that the level of situation awareness is lower in conjunction with higher levels of automation than with lower levels of automation (Endsley, 1996; Kaber & Endsley, 2004), which lead to challenges for operators to detect potential system failures. This would reduce their ability to retake control over of the system, and recover from these system failures. Thus, it is important to evaluate the differences in drivers' responses to the failures of driver support systems in different levels of automation.

Operators' characteristics and attitudes towards the automated system have also been suggested as important factors that affect driving performance when automated systems fail. One study has found that people who are more cooperative with others are less likely to cooperate with robotic systems (i.e., automated systems) (Ross, 2008). Automation complacency is defined as operators' overconfidence in automation and low index of suspicion and supervision of automated system functions (Parasuraman & Manzey, 2010). Automation complacency has been shown to reduce operators' awareness of the system state and result in poor responses to automation failures (Singh, Molloy, & Parasuraman, 1993b; Bailey & Scerbo, 2007). Therefore, it is valuable to determine how these characteristics and attitudes towards the automated systems affect driver' responses to the failures of automated DSSs in different levels of automation.

It has been suggested that when drivers are using both the ACC and LK systems, they are more willing to be involved in non-driving tasks and engaged in risky behaviors, such as extended glances away from the forward roadway, compared to when they were driving only with ACC engaged (Llaneras, Salinger, & Green, 2013). Playing with audiovisual entertainment systems, including portable TV and DVD players, are important in-vehicle non-driving tasks to drivers. So far, no study has investigated the effects of using the audiovisual entertainment and DSSs (specifically the ACC and LK systems) simultaneously on driving responses to a DSS fails. Suzuki and Jansson (2003) suggested that lane departure warning improves drivers' safety when the vehicle drifted to the edge of the lane in manual driving conditions. However, drivers' roles have been changed from a system operator to a system supervisor in highly automated vehicles (Rasmussen, 1981). They tend to have more risky behaviors and poorer responses to safety critical events, such as higher likelihood of engagement in non-driving tasks, compared to when they are manually driving the vehicles (Merat et al., 2012; Llaneras et al., 2013; Xiong & Boyle, 2013). It is not well known if the lane departure warnings effects from other studies with manual driving translate into driving with semi- or fully-autonomous vehicles.

All automated systems are likely to experience system degradations and malfunctions which refer to not only the likelihood of the malfunction of software or hardware, but also the misuse of automated systems in the situations where the automated systems are not designed to use (Parasuraman & Riley, 1997; Parasuraman, Sheridan, & Wickens, 2000). It is important to understand how these system failures affect the human-vehicle interaction and how drivers can respond to these unexpected events. This is especially important as we move towards partially- and fully-autonomous vehicles. Therefore, the overall goal of this research is to develop the understanding of how drivers' responses are affected when an automated DSS fails in various situations.

Specific aims

- AIM 1: *Determine if drivers' performance differs when a LK system fails with two different levels of automation.* Data from a driving simulator study were used. Participants' performance from two different levels of automation was compared to ensure that drivers performed worse when facing the failures of The LK system in a higher level of automation.
- AIM 2: *Investigate the effects of engaging in non-driving tasks when a DSS fails*. Drivers with both the ACC and LK systems engaged are more likely to be involved in non-driving task and engage in risky behaviors. Data from a driving simulator study were used to ensure that the effects of non-driving tasks (watching video clips) on drivers' performance when they were experiencing induced drifts while engaging the ACC and LK systems result in severe safety critical events.
- AIM 3: *Estimate the effects of lane departure warnings on drivers' responses to a LK system failure when drivers are using both the ACC and LK system.* Drivers with both

the ACC and LK systems engaged perform worse when facing the lane departure events following the failure of the LK system. Data from a driving simulator study were used to determine that the effect of lane departure warning on drivers' responses to the lane departure events following the failures of the LK system with both the ACC and LK systems engaged.

- AIM 4: *Evaluate the relationships between drivers' characteristics and attitudes towards automation and their responses to automation failures.* Four surveys were used to assess the participants' automation complacency and interpersonal trust, acceptance, and trust on the LK system in the study. The four surveys and their associated responses to the LK system failures provided insights on the relationship between drivers' characteristics and attitudes towards automation and their driving performance when a DSS fails.

Those four aims together provide insights into the factors that potentially affect drivers' performance with different levels of automation when a LK system fails. Although only the failure of the LK system was considered in this dissertation, the design of the study, analysis method, and results can be generalized to studies that investigate the effects of the failures of other DSSs on driving performance. Chapter 2 presents the relevant literature related to levels of automation, operators' characteristics, driver distraction, and their expected influence on driving performance. Chapter 3 provides the result of first conducted on the driving simulator to address the AIM 1. Chapter 4 provides the result of second experiment to address the AIM 2. Chapter 5 presents the results of the comparison of second and third experiments to address the AIM 3. The surveys to assess the participants’ automation complacency, interpersonal trust, acceptance, and trust on the LK system were distributed to participants in all three experiments and the AIM 4 is addressed with Chapter 3, 4, and 5. Chapter 6 describes the general conclusions of this research and the direction of the future study.

CHAPTER 2: BACKGROUND

The goals of this research are to understand how semi-autonomous vehicles and non-driving tasks influence drivers' responses to the failures of semi-autonomous vehicle components and evaluate the effects of audible lane departure warnings on drivers' responses to lane departure events in semi-autonomous vehicles. The first step to achieve this goal is to understand the characteristics of automation and the potential problem induced by automated systems in different application areas. This chapter summarizes the literature in this area and identifies the research gaps that this dissertation will address.

Automation and levels of automation

Technical development of computer software and hardware makes it possible to automate many aspects of systems (Parasuraman et al., 2000). Currently, automation is widely applied across many domains and industries, such as health care, nuclear station, aviation, and ground transportation. Automation refers to the mechanical or electrical apparatus, process, or system that partially or fully replaces human operators in some specific tasks (Wickens, 2008). Automation is particularly useful for domains in which the task is at the limit of human physiological or cognitive abilities (e.g., aviation, nuclear energy, mining, transportation) (Endsley 1996; Bonnie 1994; Sheridan 1992; Scheding et al. 1999) or unsafe for humans (e.g., aerospace, undersea) (Fukunaga et al. 1997; Albus 1995).

Regardless of the variety and widespread implementations of automation, the benefits of automation to operators' well-being and system safety have not been well established. Some studies have shown that automation does not simply surrogate human operators and it also changes the working procedures unintended and unanticipated, as a result induces new coordination demands on human operators (Wiener & Curry, 1980; Bainbridge, 1983; Chambers & Nagel, 1985; Parasuraman, 1987; Sheridan, 1992). Automation refers to full or partial replacement of human activities, which indicates that the automation can vary across the continuum levels, from the lowest level (i.e., human takes all decisions and actions with no automated-system assistance) to the highest level (i.e., automated-system replaces humans to make all decisions and actions with the human out of the control loop) (Riley, 1989; McGee et al., 1998; Parasuraman et al., 2000). In an advanced automated system (high levels of automation), individuals are transitioned from system operators to system monitors or managers (Kessel and Wickens 1982). The human operators who monitor the automated system may be unaware of critical features of system states, which could lead to critical safety situations (Endsley 1996). Some studies suggest that the negative effects as a result of the automation, such as mental workload increase, decrease in situation awareness, automation complacency, and skill degradation (Wiener, 1988; Rose, 1989; Singh et al., 1993b; Endsley & Kiris, 1995; Parasuraman & Riley, 1997; Kaber, Omal, & Endsley, 1999; Kaber & Endsley, 2004). The research and resulting system safety from these and other domains can be used to improve and build a better expectation of the use of automation in surface transportation vehicles.

Automation in vehicles

Automation in vehicles has becoming popular recently. It aims to improve drivers' comfort and transportation safety. Stanton & Marsden (1996) identified that human errors constitute a major factor of traffic crashes, and proposed that if drivers could be removed from the control loop, it may ultimately reduce the traffic crash rates and improve transportation safety. In addition to the concern of road safety, automated driving also improves drivers' well-being (Stanton & Marsden, 1996). With increasing levels of automation in vehicle, drivers cede more driving tasks to automation. There are five continuum levels of automation, ranging from level 0 (i.e., manual driving) to level 4 (i.e., fully autonomous vehicles) (Blanco et al., 2015) as shown in Figure 1. Drivers at level 0 automation vehicle manually operate the vehicle controls (brake, steering, throttle, etc.). Automation at level 1 assumes limited control from the primary controls of the vehicles. Drivers at level 2 automation cede two primary control of the vehicle to automated systems in certain limited situations. However, drivers are still responsible for supervising the function of the automated systems and are expected to regain control of the vehicles at any time with/without a notice. Vehicles at level 3 automation allow drivers to cede full control of the vehicles to the automation. Drivers are not required to supervise the automation and are expected to take control of the vehicle occasionally, but with sufficient transition time. Drivers in level 4 automation vehicles are not expected to control the vehicles at any time during a trip as these vehicles by design, do not have controls (e.g., steering wheels and pedals). Therefore, the vehicle performs all driving and safety-critical functions.

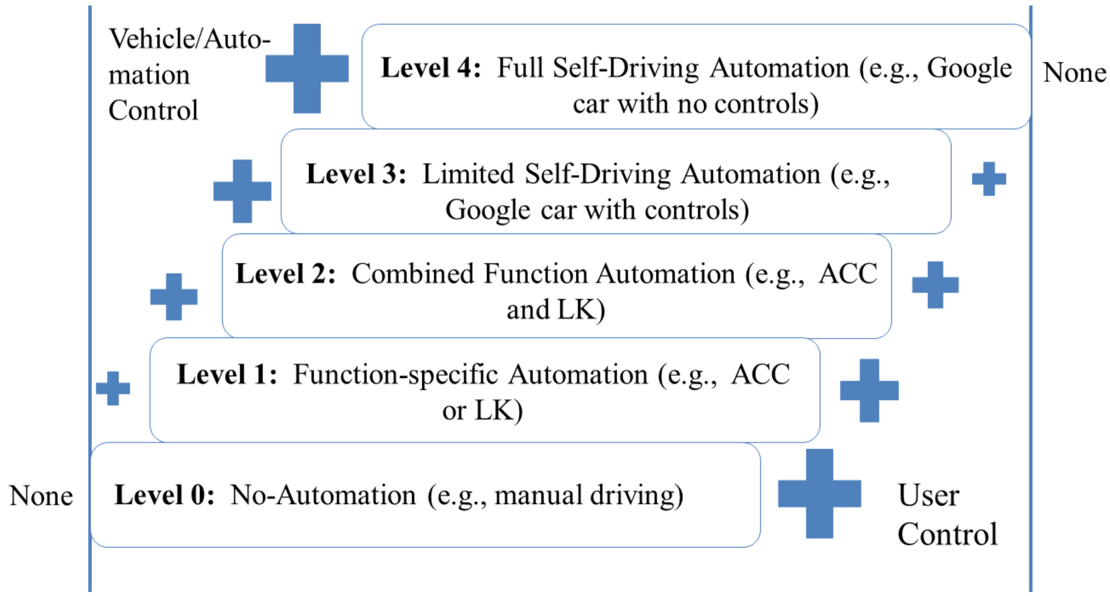
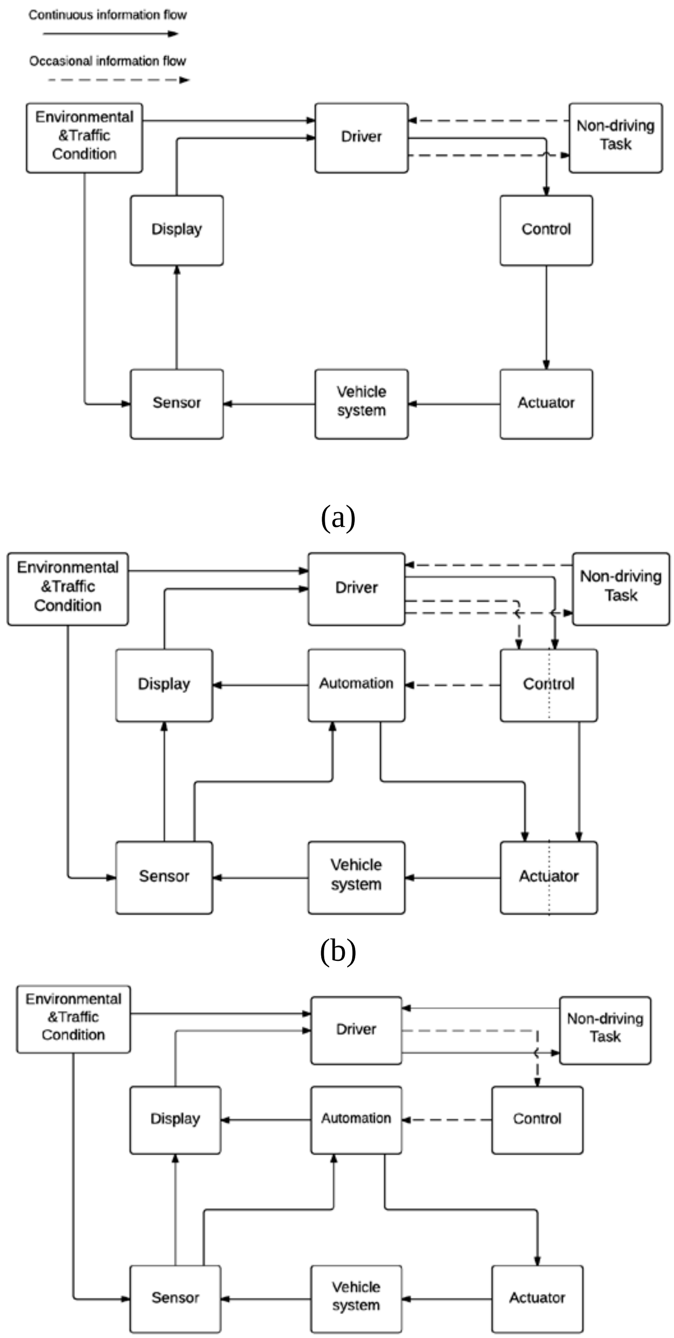


Figure 1. The NHTSA Automation levels modified from Blanco et al. (2015)

Figure 2 (a, b, and c) shows the flow of information among drivers, vehicles, the driving environment and the automation. Figure 2 (a) shows the loop of information associated with manual driving (level 0). Figure 2 (b) shows the loop of information associated with level 1. Figure 2 (c) shows the flow of the information in a semi-autonomous vehicle (level 2 and 3). The information flow for level 4 does not contain control module compared the information flow for level 2 and 3. With increasing levels of automation, the role of driver changes from a system operator to a system monitor. This indicates that the driver operates at a higher level of the control loop, called supervisory control loop (within which drivers only control the system when it is necessary). Without the automated system, the drivers would directly control the vehicle based on feedback from outside traffic conditions and vehicle displays. In supervisory control (level 2), the automated system controls the actuators, vehicle systems, and sensors. Drivers monitor the automated system and decide whether to take control from the system according to the feedbacks from outside traffic condition and displays from sensors and automated systems (Stanton & Marsden, 1996).



(c)

Figure 2. (a): Information flow at level 0 (within control loop); (b): Information flow at level 1 (partially out of the loop); (c): Information flow at level 2 and 3 (approximately fully out of the loop)

There are several types of driver support systems (DSSs) developed by vehicle manufacturers that are either currently available or that will be available in the near future, such as the forward warning system, lane departure warning system, adaptive cruise control system, and lane keeping system (Suzuki & Jansson, 2003; Vahidi & Eskandarian, 2003; Dagan et al., 2004). The ACC is designed to assist drivers in maintaining a constant speed which is preset by drivers and keep a preset headway from a slower lead vehicle (Xiong et al., 2012). Another promising automated system is the lane keeping (LK) system, which controls the lateral position of the vehicle within a lane (Stanton & Young, 2000). Similar to the LK system, lane departure warning (LDW) system also supports lateral behavior of the vehicle (Motoyama et al., 2000). LDW system uses cameras to monitor the distance between the vehicle and lane markers and if the vehicle drifts to the side of lane, an alert is given to drivers (Suzuki & Jansson, 2003; Mahajan & Patil, 2015). The purposes of implementing automated DSSs in vehicles are to reduce the risks of traffic crashes, enhance drivers' comfort and performance, and reduce the fuel consumption (Bishop, 2000; Vahidi & Eskandarian, 2003). When combining the use of the ACC and LK systems, the longitudinal and lateral positions of a vehicle are under the control of automation and the vehicle becomes a semi-autonomous vehicle at level 2 automation. With both the ACC and LK systems engaged, drivers tend to driver closer to the center of the road with more consistent speed (Stanton & Young, 1998). Stanton and Young (1998) also have found that drivers have the least workload when using both the ACC and LK systems than driving manually or with only ACC engaged. Thus, DSSs lead to the improvement of driving performance and the reduction of drivers' workloads.

Automated systems do not always work well across all situations. If operators do not have an understanding of the limitations of automation systems, safety critical situations could arise (Sarter & Woods, 1995; Kaber & Endsley, 2004). More specifically, Bato and Boyle (2011) and Xiong et al. (2012) have proposed that some drivers are more likely to report driving faster when using ACC and think ACC is able to work in some situations when approaching a stationary vehicle or object. Some studies have also found that drivers who believe that ACC could always maintain a steady headway and constant speed could fail to regain the control of the vehicle from ACC and result in forward collisions if there is an urgent safety critical event to which ACC cannot respond efficiently (Stanton et al., 1997; Stanton & Young, 2000). Drivers who did not understand the limitations of ACC were more likely to exhibit dangerous behaviors, compared to those who were aware of the ACC limitations (Dickie & Boyle, 2009).

Out-of-the-loop issue in automation

Kessel and Wickens (1982) suggested that improving technology in computers and their applications into various settings can induce an inevitable redefinition of operator roles. In such advanced automated system, the roles of pilots (Curry & Weiner 1980) and nuclear reactor operators (Rasmussen, 1981) have changed from operators (who directly control systems) to automated system monitors (who supervise the automation to control systems). Humans are less likely to be aware of the status and changes of the surroundings when the status and changes are under the control of the automation than when they control the status and make the changes themselves (Endsley & Kiris, 1995;

Sarter, 1995; Endsley, 1999). The out-of-the loop problem associated with high levels of automation could impair operators' abilities to detect the safety critical events and result in degradation of operators' behaviors (Endsley & Kiris, 1995; Endsley, 1996; Kaber et al., 1999). The role of operators working with automated system is considered as a passive information acceptor instead of an active information processor, which adds difficulties in detecting system failure and understanding the system problems, and makes it harder for operators to take control of the automated system and recover from system failures (Endsley, 1996).

It has been identified that the out-of-the-loop problem could result in degraded drivers' behaviors in the transition from automated driving to manual driving, when automation fails or degrades in performance and it requires drivers to reclaim the control of the vehicle from the automation (Saffarian, De Winter, & Happee, 2012). For example, Young and Stanton (2000) suggest that it is more difficult for drivers to detect and recover from automation failure (the period from detecting the failure, to manually control the vehicle, to following the lane at appropriate speed) when drivers are in higher level of in-vehicle automation. They found that the collision rates were higher when ACC failed at the same moment as safety critical issues with both the ACC and LK systems engaged (which is at level 2) than that in only ACC system (which is at level 1). They also found that the levels of driver skill (learner (currently learning but does not hold a full license) and expert (holds a full driving license) might influence responses to automation failure. A study conducted by Nilsson (1995) aimed to evaluate how drivers respond if the ACC fails to detect the vehicles in front of the participant. They found that participants in an ACC group had larger portion of collision than those in manual driving group. Similarly, it has been suggested by Rudin-Brown, Parker, and Malisia (2003) that drivers with ACC engaged were more likely to have a larger reaction time to lead vehicle braking events compared to the those without ACC engaged. Furthermore, the non-driving tasks would also worsen drivers' responses to the forward collisions in highly automated vehicles (Gold, Berisha, & Bengler, 2015). When steering is automated (as with a lane keeping system), Desmond, Hancock, and Monette (1998) found that drivers' lateral control of the vehicle was impaired when drivers need to take over control of the vehicle following an automation failure.

In addition, it has been suggested that when drivers were using both the ACC and LK systems (at level 2 automation), they were more likely to be involved in non-driving tasks and engaged in risky behaviors, such as extended glances away from the forward roadway, compared to when they were driving only with ACC engaged (at level 1 automation) (Llaneras et al., 2013). The higher likelihood of involvement in non-driving tasks for drivers using both the ACC and LK systems can be associated with the lower demand of driving tasks. Drivers with lower driving task demands were more likely to be distracted by the non-driving tasks (Strayer, Drews, & Johnston, 2003).

Many studies have made efforts to propose potential solutions that can mitigate the effects of the out-of-the-loop brought by highly automated vehicles (Stanton & Young, 2000; Seppelt & Lee, 2007; Blommer et al., 2015). For example, Blommer et al. (2015) suggest that a scheduled driver engagement strategy (i.e., automated DSSs and drivers are in a scheduled rotation to control the vehicles) would also improve drivers' responses to a potential forward collision when drivers are using the ACC and LK systems (at level 2 automation). One of the potential solutions, in highly automated vehicles, is the use of information portal, which can be represented in visual displays or non-visual displays (Saffarian et al., 2012). Seppelt and Lee (2007) have proposed that providing drivers' the continuous information about the function status of ACC could improve drivers' performance when ACC fails.

Automation complacency and interpersonal trust

Studies have shown that operators' decisions about whether to utilize automated systems or to manually control systems rely on their levels of trust in the automation (Bonnie, 1994; Bishop, 2000). In other words, if they believe the reliability and performance of automated system is better than their abilities, they would prefer to use automation. Otherwise they may prefer to override automatic control. Peoples' attitudes of over-trust on automation indicate a potential for automation complacency (AC) (Bonnie, 1994). AC is defined as operators' low index of suspicion and inferior detection of system functions during the period when the system is under the control of the automation compared to those under the manual control (Wiener & Curry, 1980; Parasuraman & Manzey, 2010) and often results in an operator relying on automation even when it may not be the best strategy or when automation fails. AC tends to reduce operators' awareness of the system status and changes, particularly supervising the complicated and reliable systems when the problems are infrequent and unexpected (Bailey & Scerbo, 2007). Individuals with high complacency attitude towards automation were more likely to present poor performance when facing unexpected automation failures (Singh et al., 1993b; Payre, Cestac, & Delhomme, 2015). It has been shown that drivers after extended use of the ACC would set speed faster and shorter headway distance, and have less intervention compared to novice ACC users (Xiong & Boyle, 2013), which may indicate that drivers with extended experience of using the ACC are more likely to develop automation complacency. Singh, Molloy, and Parasuraman (1993a) developed a scale for attitudes toward automation that calibrate an individual's level of complacency. According to their results, complacency is built on trust, confidence, reliance and safety-related complacency. In other words, if drivers develop complacency to automated DSSs, it may lead serious safety critical problems when one of these devices fails on the road.

Interpersonal trust may also have effects on drivers' performance when automation fails, as people who are more cooperative with others might be less likely to cooperate with robotic systems (i.e., automated systems) (Ross, 2008). Research has shown that interpersonal trust has effects on human-machine interaction (Ross & LaCroix, 1996) and it was shown that trust also has effects on human-automation interaction (Lewandowsky, Mundy, & Tan, 2000). Indeed, people do not differentiate trust concepts across interpersonal trust and human-automation trust (Jian, Bisantz, & Drury, 2000). Thus, it is reasonable to predict that the relationship between the levels of operators' interpersonal trust and their performance during the period of system failure may exist.

Gaps in the literature

While there is a plethora of literature examining pilots' responses when faced with the failure of autopilot. Very few studies evaluate drivers' responses to the failure of automated driving support systems, especially the failures of lane keeping systems. Furthermore, it has been shown that automated DSSs decrease drivers' workload (Stanton & Young, 1998) and if drivers have more spare cognitive resources from primary driving task, they could be more involved into non-driving related tasks (Young, Regan, & Hammer, 2007). One of the non-driving tasks is the drivers' interactions with the audiovisual entertainment systems, such as in-vehicle DVD players, which are becoming popular in-vehicle devices in the United States (TI, 2001). At level 2 or 3 automation, drivers may be more willing to use the DVD players (or a portable tablets), as they have lower driving demands when supervising the functions of the automated systems. Though the legislation of the United States forbids the use of screen (which is not designed to assist drivers) mounted within drivers' field of views, it is still possible that an in-vehicle display is attached to the center console after the purchasing the vehicle (Young, Lee, & Regan, 2008). In highly automated vehicles, drivers may be more willing to use the DVD players (or a portable tablets), as they have lower driving demands when supervising the functions of the automated systems. There have been many studies that evaluate the effects of the non-driving tasks on driver performance (Lam, 2002; Sheridan, 2004; Bunn et al., 2005; Donmez, Boyle, & Lee, 2006; Kass, Cole, & Stanny, 2007; Young et al., 2007; Koppel et al., 2011; Beanland et al., 2013). However, the results and implications of these studies apply in the situations in which drivers manually control the vehicle (i.e., when drivers are within control loop). With the emergence of more automated DSSs, it is worthwhile to determine if the results translate as drivers transition into supervisory roles in autonomous vehicles (i.e., when drivers are out of control loop). In addition, numerous studies have shown that audible lane departure warnings assist drivers in improving their responses to potential lane departure events when drivers are drowsy or engaged in a non-driving task (Ziegler et al., 1995; Motoyama et al., 2000; Suzuki & Jansson, 2003). However, drivers' behaviors may be altered by highly automated vehicles (Merat et al., 2012; Llaneras et al., 2013; Xiong & Boyle, 2013). It is not well known if the lane departure warnings effects are consistent between manual driving conditions and highly automated driving conditions.

Specific aims

Drivers' responses to the failure of the LK system will be addressed with four specific aims: (1) examining the effects of level of automation on drivers' performance when LK fails, (2) examining the effects of non-driving tasks on drivers' responses when there is an induced drift while drivers are using LK system, (3) evaluating the effects of an audible warning on drivers' responses to the lane departure events associated with the failure of LK system and determine if the effects of an audible warning to the lane departure events were consistent between manual driving conditions and highly automated conditions, and (4) examining the relationship between drivers' attitudes towards automation and personal characteristics and their driving behaviors during the failure of the LK system. The first specific aim of this dissertation assesses the effects of level of automation on drivers' performance when the LK system fails (Chapter 3). The second specific aim of this dissertation assesses the effects of level of automation and non-driving tasks on drivers' performance when there is an induced drift while drivers are using the ACC and LK systems (Chapter 4). The third aim of this dissertation examines the mitigated effects of an audible alert to lane departure event on drivers' performance when there is an induced drift while drivers are using the ACC and LK systems (Chapter 5). Specific Aim 4 assesses the relationship between drivers' attitudes towards automation and personal characteristics and their driving behaviors during the failure of the LK system (Chapter 6).

CHAPTER 3: ASSESSING DRIVERS' PERFERMANCE WHEN DRIVER SUPPORT SYSTEMS FAIL AT DIFFERENT LEVELS OF AUTOMATION

The work presented in this chapter addresses the Specific Aim 1 of this dissertation through three objectives, to examine: (1) how drivers' performance differs when the lane keeping (LK) system fails at two different levels of automation (lower level with only the LK system engaged (level 0) and higher level with both the ACC and LK engaged (level 2)), (2) how drivers respond to automation failures in three different road conditions (straight roadway, curvy roadway, and straight roadway with high traffic), and (3) how drivers' characteristics and attitudes, such as the operators' complacency, interpersonal trust, and their trust and acceptance of the LK system, would influence driving performance during the system failures. The first object demonstrates the fact that operators in higher level of automation (at level 2 automation) have poorer performance when automated systems fail is true with respect to drivers. The work of this chapter was presented in Human Factors and Ergonomics Society Annual Meeting in 2014 (Shen & Neyens, 2014).

Methods

Participants

Forty-eight participants with valid U.S driver's license for at least one year were recruited for this study. All participants were native or fluent English speakers. Twelve participants were excluded because they either did not engage or reengage the LK system, they experienced experimental error, and one participant fell asleep during the experimental drive. Therefore, the data collected from thirty-six participants (range 18-25 years, mean=21.19, sd=2.99) were used for data analysis.

Apparatus

The study was conducted using a National Advanced Driving Simulator (NADS) MinSim driving simulator maintained by the Ergonomics and Applied Statistics Laboratory at Clemson University. The Minsim is a ¼ cab with integrated video and data collection tools. The system also has the ACC and LK system models incorporated into the vehicle dynamics model to allow for studies relating to the impact of these systems on driving performance and safety. Figure 3 is the picture of the MinSim driving simulator (see Ranney et al. (2002) for further description of NADS MiniSim configuration). Figure 4 shows the buttons that are used to set the ACC and LK systems. Figure 5 illustrates the lights on dashboard which mean to indicate the status of the ACC and LK systems. Participants sit on the simulator and press the ACC setting button (the button left to the steering wheel in the middle of “+” and “-” buttons, and then use “+” or “-” button to set the speed of ACC and “∨” and “∧” buttons to set the headway. The LK system switch is on the right of steering wheel with two lines. In Figure 5, the vehicle is at 60 mph with medium headway setting and the LK system is engaged.

Figure 3. MinSim driving simulator

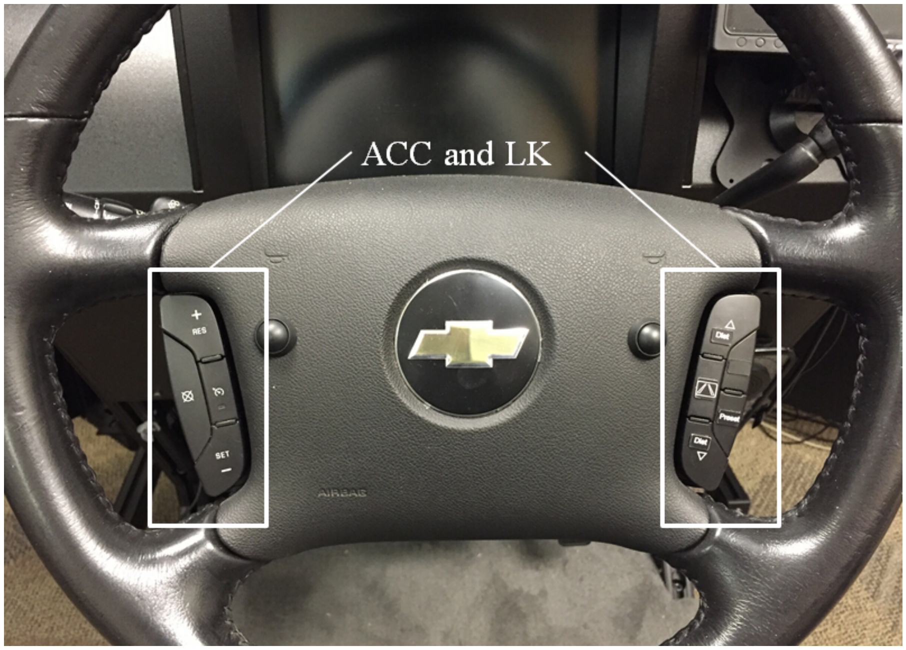


Figure 4. Settings of the ACC and LK systems

Figure 5. The ACC and LK systems status indicating light

Procedures

Upon arrival, participants were given a brief introduction to this experiment and completed an informed consent process approved by Clemson University (IRB# IRB2013-123). The participants were assigned into one of the two conditions; one in which the participants would drive with only the LK system engaged and in the other, the participants would drive with both the ACC and LK systems engaged. The participants completed the Potential Complacency Rating Scale (Singh et al., 1993a) and the Interpersonal Trust Scale (Rotter, 1967) questionnaires. Before the experiment, each participant had two practice drives: one to gain experience driving the simulator manually and the other to gain experience with the automated systems. The experimental drive took 15 minutes and participants were asked to keep the LK system (and the ACC, if applicable) engaged as much as possible. After the experimented drive, the participants completed several surveys.

Experiment Design

This experiment is a 2×3 repeated measures design with level of automation (two levels) as a between-subjects factor and road condition (three conditions) as a within-subjects factor with repeated measures. The significant level for this study is $\alpha=0.05$. The analysis was done using the aov function in R version 3.0.2.

Independent variables. There was one between subjects factor (two levels of automation) in this experiment. In the first condition only the LK system was engaged and the LK system failed and in the second condition both the ACC and LK systems were engaged but only the LK system failed. Each participant experienced three failures of the LK system (within subject factor); one on a straight road without traffic nearby, one on a curve road without traffic nearby, and one while in traffic on a straight road. All of the failures were accompanied by an auditory two-beep alarm. The sequence of the failures was counterbalanced to control for the learning effects of failures on straight road and on a curve road. The failure in traffic was always last as it presented a greater opportunity to crash.

Complacency towards the automation was measured using the Complacency Potential Rating Scale (CPRS) (Singh et al., 1993a). The level of interpersonal trust was measured using the Interpersonal Trust Scale (ITS) (Rotter, 1967). Participants' Acceptance Scale (AS) (Van Der Laan, Heino, & De Waard, 1997) and Trust Scale (TS) based on Jian et al. (2000) were also used. All the scales used in this experiment were measured by a 5-point Likert-type scale with anchors ranging from strongly disagree (1) to strongly agree (5).

Dependent variables. The drivers' performance was quantified by responses time (second), maximum lane deviation (feet), maximum steering wheel angle (degree), and standard deviation of steering wheel angle (degree). The responses time was the time duration between the start of failure alarm and the time of first reacting action taken by the participants. For the participants assigned to the condition of low level of automation (i.e., only the LK system engaged), their first action could be releasing the accelerator or manually steering. For the participants assigned to the condition of the high level of automation (both ACC and LK systems engaged), their first action could be either pressing the pedal or steering the wheel. Maximum lane deviation is the maximum distance between the center of the vehicle and the center of the lane. Maximum steering wheel angle is the maximum absolute value of the difference of the steering wheel angle between its initial direction and its directions throughout the failure. Standard deviation of steering wheel angle is the standard deviation of the steering wheel angle throughout the failure. Better driving performance during the LK failure is represented by shorter responses times, smaller maximum lane deviations, smaller maximum steering wheel angles, and smaller standard deviations of maximum steering wheel angle.

Results

Participants' complacency potential rating scale (CPRS) (range 35~56, median=46.5), interpersonal trust scale (ITS) (range 37~69, median= 54), acceptance scale (AS) (range 9~43, median= 34), and trust scale (TS) (range 3~14, median=10) were used to measure participants' characteristics. The survey responses scores were categorized using a median split to categorize the participants into either a higher or lower group for each construct. Bonferroni multiple comparisons were used to further pairwise compare the factors of road condition, if it had a significant effect on drivers' performance. As there were three different road conditions and three comparisons, the significant level is 0.05/3=0.017 for comparisons of road conditions. There were no significant differences between the characteristics and attitudes towards automation systems (i.e., CPRS, ITS, AS, and TS) for participants assigned to the two conditions.

Thus, participants' characteristics and attitudes towards automation were not significant confounding factors across the factor levels of automation.

Responses Time and Responses Behavior

The level of automation ($F_{1, 106}$=40.79, p=0.001) significantly predicted responses times with longer reaction times for the level 2 automation condition (with both the ACC and LK systems engaged) than the level 1 automation condition (with only the LK system engaged) (Figure 6). No other factors had significant effects.

For the participants in the low level of automation condition, 94% (17 out 18) of them released the accelerator pedal before taking over control of the steering wheel. For the participants in the high level of automation condition, all of them took over control of the steering wheel before pressing either pedal, and 83% (15 out of 18) of them did not hold the steering wheel while regular driving.

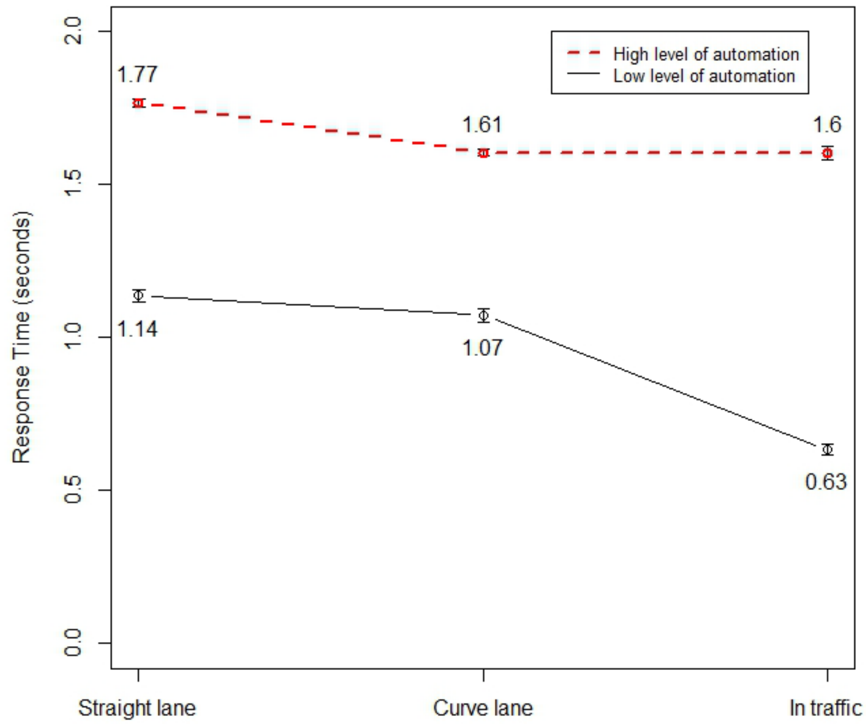


Figure 6. Reaction time (and standard error bars)

Maximum Lane Deviation

There were two significant predictors of maximum lane deviation: the level of automation ($F_{1, 105}$ =4.344, p=0.0396) and ITS ($F_{1, 105}$=4.239, p=0.0420). Figure 7 shows the average maximum lane deviation on two levels of automation across the three road conditions. The mean value of maximum lane deviation in a high level of the ITS is 2.94 feet versus 2.38 feet in a low level of ITS.

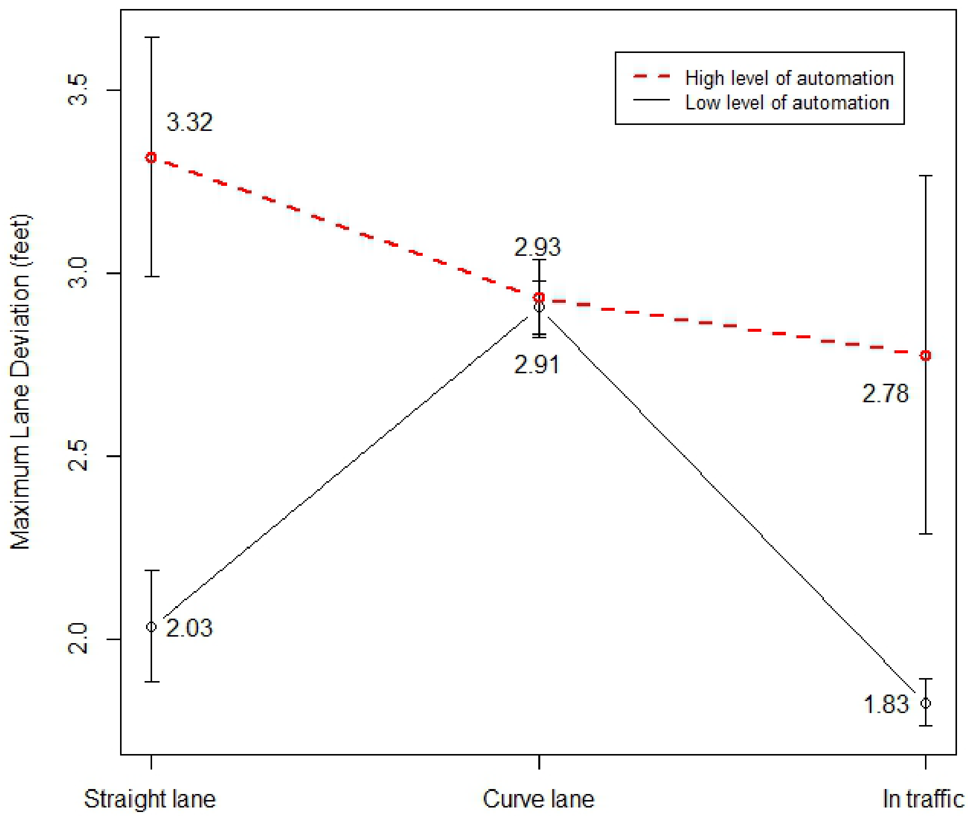


Figure 7. Maximum lane deviation (and standard error bars)

Maximum Steering Wheel Angle

The road condition ($F_{2, 68}$=4.087, p=0.0211) was the only significant factor of maximum steering wheel angle. Bonferroni pairwise t-test (assuming the variance of maximum steering wheel angle is different) was used to compare the maximum steering wheel angle in the three road conditions, straight lane versus curve lane ($t_{68.86}$= -1.05, p=0.30), straight lane versus in traffic ($t_{68.91}$= 1.59, p= 0.12), and curve lane versus in traffic: ($t_{70.00}$=2.83, p<0.01) (Figure 7).

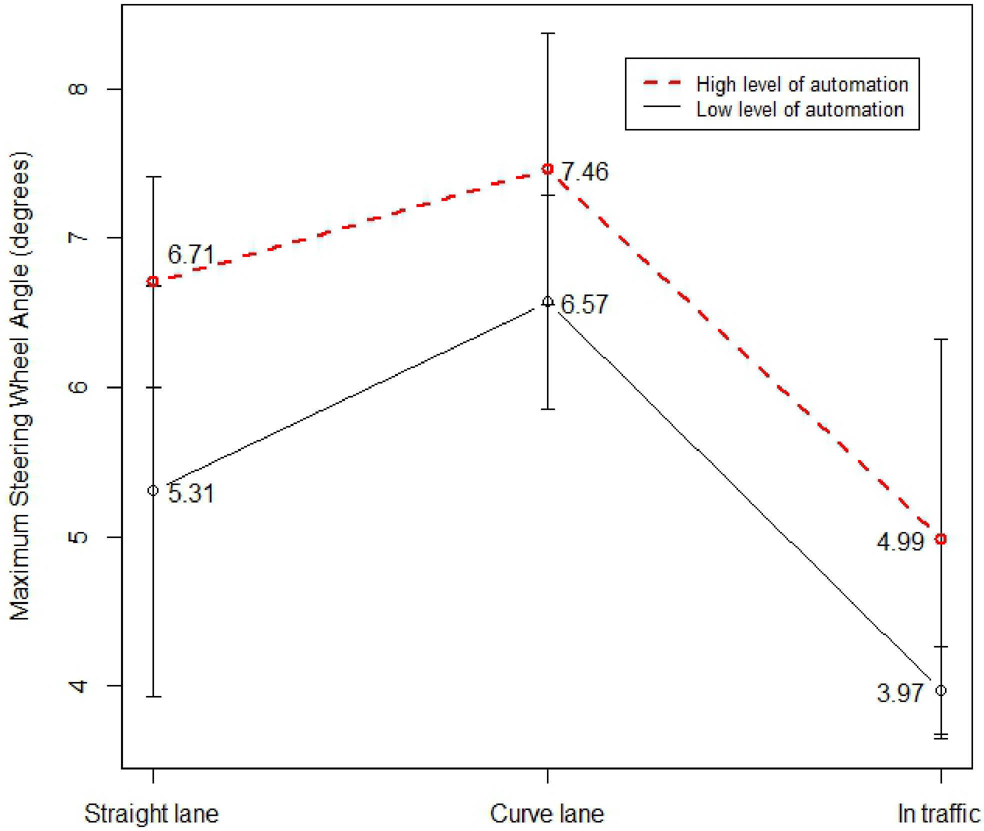


Figure 8. Maximum steering wheel angle (and standard error bars)

Standard Deviation of Steering Wheel Angle

The statistical model showed that road condition ($F_{2, 68}$=5.693, p=0.0052) was the only significant factor that predicted the standard deviation of steering wheel angle. Bonferroni pairwise t-test (assuming the variance of maximum lane deviation was different) was used to compare the standard deviation of steering wheel angle in the three road conditions, straight lane versus curve lane (t_{70}= -1.78, p=0.08), straight lane versus in traffic ($t_{69.60}$= 1.46, p= 0.15), and curve lane versus in traffic ($t_{69.57}$=3.31, p<0.01).

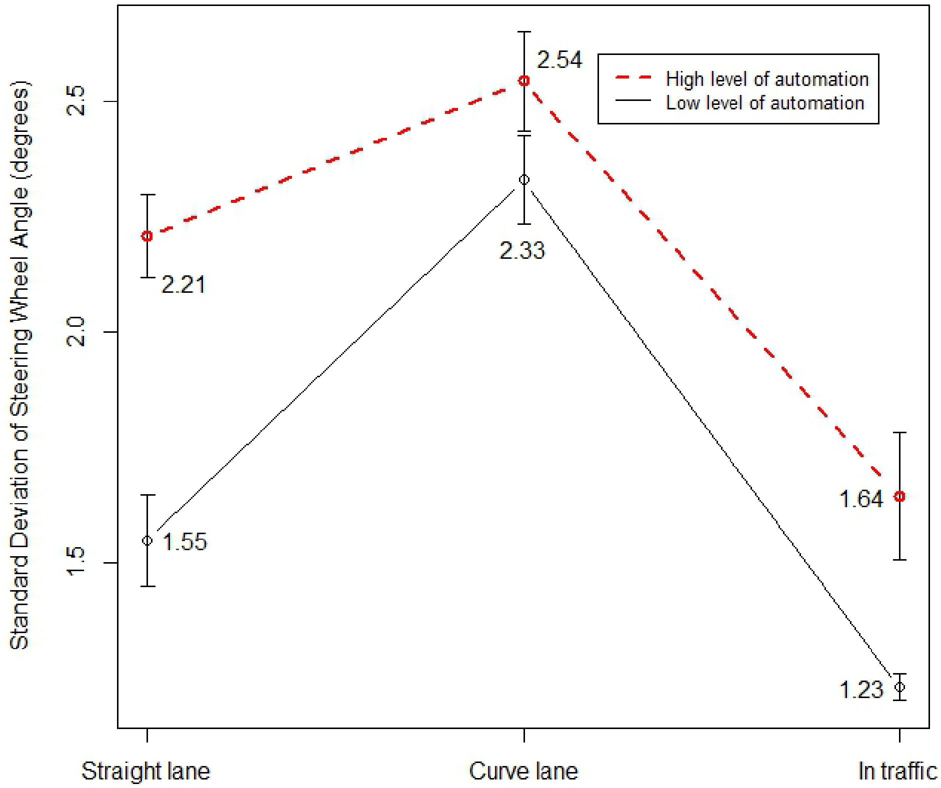


Figure 9. Standard deviation of steering wheel angle (and standard error bars)

Discussion

The purpose of this study was to investigate whether levels of automation significantly affected drivers' performance during automation failures. Drivers in the level 2 automation condition tended to have a longer responses time to the failure of the automated system compared to drivers in the lower level of automation condition. This finding was consistent with the results obtained by Young and Stanton (2000) that drivers in the higher level of automation condition (especially inexperienced drivers) were more likely to have a longer responses time. In terms of maximum lane deviation, the higher level of automation had a significant negative effect on driver performance. The participants in the level 2 automation condition had a significantly larger maximum lane deviation than those in the level 1 automation condition. Most of the participants in the lower level of automation condition released the accelerator, which reduced the speed of the vehicle during the period of the LK system failure. In the level 2 automation condition, the speeds of the vehicle were controlled by ACC and kept at 65 mph during the LK system failure, which may partially explain why the participants in the lower level of automation condition had the smaller maximum lane deviation. Besides the level of automation condition, interpersonal trust was another significant factor that influenced drivers' maximum lane deviation in this study. Consistent with Ross (2008), the results suggest that drivers' who trust others more might have poorer performance when faced with the failure of automation.

The level of automation was not a significant predictor of maximum steering wheel angle and standard deviation of steering wheel angle. One possible reason was that as the experiment drive was only about 15 minutes, the participants may have been able to stay vigilant during the driving tasks and the simulator did not change state drastically during a failure, so the vehicle did not veer substantially in one direction or the other.

Kaber and Endsley (2004) proposed that operators working with high levels of automation tend to have lower vigilant levels. Although no specific data was collected related to drowsiness, several participants exhibited drowsy behavior (e.g., frequent yawning) and one participant fell asleep during the experiment and was excluded from the analysis. With the increasing use of automated systems, the role of the driver transitions to that of monitoring the vehicle. Desmond et al. (1998) found that automated driving could induce fatigue just as monotonous driving. Thus, for future autonomous vehicles (e.g., fully automated vehicle), it is important assess the impact of vigilance, driver impairment, and the impact of the reliability of the automated systems.

As expected, there were differences in the driving performance measures with larger maximum steering wheel angle and standard deviation of steering wheel angle during the curved road automation failure than during failures in the other two road conditions. One possible reason was that it is more difficult to steer and correct steering on curved roads than on straight roads (Salvucci, Boer, & Liu, 2001).

The drivers' Complacency Potential Rating did not have a significant effect on the four independent variables and the conclusion that drivers' complacency attitude would affect their performance when faced with the automation failure could not be validated. In this study, the experimental drive was only 15 minutes and that might not be long enough to develop complacent behaviors. Additionally, the acceptance of the LK system and trust of the lane keeping system were not significant predictors of drivers' performance. However, some studies in other areas have proved that users with more experience with a product or service (e.g. cell phone and internet banking) were more likely to accept and trust the product or service (Wang et al., 2003; Kaasinen, 2005).

Limitations

There are limitations that need to be considered when interpreting these results. The drivers' responses were potentially different between the two conditions. Drivers could respond to the system failures in different ways (i.e., initially steering, braking, or releasing the accelerator pedal) when they were either using the accelerator pedals or relying on the ACC system to control the longitudinal motion of the vehicle. Additionally, all the participants in this study were younger drivers (18-25-years old). Young people are more likely to accept new technologies and tend to have better performance when using the technologies (Czaja et al., 2006; Czaja & Lee, 2007). Thus, the results of this experiment may not generalize to other driver groups.

As mentioned earlier, the experiment drive was only 15 minutes. Participants were potentially able to concentrate on the driving tasks throughout the experiment. Moreover, before the study, the participants were informed that there might be system failures in the experiment drive. This may not reflect the real world in which drivers using the automated system drive on longer trips and may not be able to anticipate the likelihood, timing, or location of system failure, which may result in vigilance decrement (Mackworth & Taylor, 1963; Warm et al., 1992). The vigilance decrement may also be associated with distracting tasks. It may be more likely for drivers with higher levels of automation condition to be distracted, which might lead to more significant differences in recovery from system failures.

Conclusion

In general, this study indicates that a higher level of automation in vehicles may lead to poorer performance when faced with automated system failures. Drivers performed worse on the curvy road, as it was more difficult for them to maintain their lane position when faced with the LK failure. Drivers' level of interpersonal trust affected their performance when faced with the LK failure with higher level of interpersonal trust leading to poorer performance when recovering from system failures. Recognizing these facts will help designers of in-vehicle automated systems enhance the system design and also help policy-makers develop effective training programs for future autonomous vehicles to improve driving safety.

CHAPTER 4: ASSESSING DRIVERS' RESPONSES DURING AUTOMATED DRIVER SUPPORT SYSTEM FAILURES WITH NON-DRIVING TASKS

This chapter describes the design of the experiment to address the second aim of the dissertation. Specifically, the objective of this experiment is to investigate the effects of non-driving task (watching video clips) on drivers' performance when the LK system fails when drivers are in the level 2 automation condition. Younger drivers may have less experience and may not have effective strategies to distribute the attention between driving task and non-driving task (Regan, Deery, & Triggs, 1998), have shown to perform worse when they are involved in non-driving tasks while driving (Young et al., 2007) but are more likely to accept new technologies (Czaja et al., 2006; Czaja & Lee, 2007), younger drivers may have a higher risk than older drivers when one automated driver support system (DSS) fails while they are engaged in non-driving tasks. Thus, the participants for this study are also younger drivers (between 18-25 years old).

Methods

Participants

Fifty-five native English speakers who held a valid U.S driver's license at least for one year and drove at least three times per week participated in this study. Seven participants were excluded from the analysis, as two of them failed to respond to the critical safety events when there was an automated system failure, four of them experienced experimental errors, and one participant withdrew due to experiencing some aspects of simulator sickness during the experiment. Therefore the final sample included 24 males and 24 females between 18-25 years (M=21.17, SD=1.91). One participant in the final sample had ever used the ACC and LK systems.

Apparatus

The study was conducted using a National Advanced Driving Simulator (NADS) MinSim driving simulator maintained by the Ergonomics and Applied Statistics Laboratory at Clemson University (A more detailed description of a standard NADS MinSim driving simulator can be found in Xiong et al. (2012)). A 7-inch LCD monitor was used as an in-vehicle display and was attached to the right of the steering wheel. The center of the display was approximately 25 cm from the center of the dashboard display and 3 cm from the top of the dashboard display. The angle of the in-vehicle display could be adjusted by the participants as needed. The arrangement of the in-vehicle display is in Figure 10.

Figure 10. Arrangement of in-vehicle display on driving simulator

Procedures

Upon arrival, participants were given a brief introduction to this experiment and completed an informed consent process approved by Clemson University (IRB# IRB2014-398). As components of the non-driving task required color vision, participants' color vision was assessed using Ishihara color blindness test plates. Then the participants were given a detailed introduction to this experiment. For the participants in the higher level of automation condition, they were also instructed how to use the ACC and LK systems and stop the functioning of those systems. They were told to keep the ACC and LK systems as much as they can unless they thought it was necessary to stop the systems, but they were not told there would be failures of the LK system. After that, the participants completed two questionnaires: the Potential Complacency Rating Scale with 12 items (Singh et al., 1993a) and the Interpersonal Trust Scale with 25 items (Rotter, 1967). Before the experimental, each participant completed one practice drive to gain the experience with the driving simulator. The experimental drive took approximate 30 minutes and participants were asked to follow the audio directions provided within the driving scenario. After the experimental drive, participants who drove with the ACC and LK systems engaged completed the acceptance scale and trust scale for the LK system. The acceptance scale was modified based on Van Der Laan et al. (1997). This scale was composed of nine questions. The trust scale was based on the trust questionnaire developed by Donmez et al. (2006). In addition to the two statements for trust measure used in Donmez et al. (2006), another statement that was also used to measure if drivers' prefer to use the LK system in the future after they experiencing the failure of the LK system. Three statements were used from the scale were "I trust the LK system", "The performance of the safety enhanced my driving", and "I prefer to use lane keeping on Interstates or freeways". In both drives, participants were asked to set the speed in ACC or drive at 65 mph (104 kmh).

Experiment design

This experiment was a 2×2 repeated measures design (mixed factorial design) with two automation conditions (the manual driving condition (the level 0 automation condition) and the automated driving condition with both the ACC and LK systems engaged (the level 2 automation condition)) as a between-subjects factor and two non-driving task status (watching video clips, absence of watching video clips) as a within-subjects factor. The scenarios of the practice and experimental drives were rural inter-state freeways with a low density of traffic on drivers' side and a steady flow on oncoming traffics. Thus, though the vehicles drifted outside the lane in the lane departure events, no collision would occur.

An in-vehicle display was mounted at the right side of the dashboard on the driving simulator. The participants were asked to watch movie clips that ranged from 40 seconds to 1 minute on the in-vehicle display throughout the experimental drive. The movie clips were pieces cut from an American movie. In order to evaluate whether participants were engaged in the non-driving task, the participants were told that there were multiple choice questions about the content of the movie following each movie clip, and that the score on these questions provided an assessment of engagement in the tasks. Each question assessed a visual or situational aspect of the video that would require the participant to devote their attention to watching the video to be able to answer them correctly. All the questions were perceptual and straightforward, such as "What is the color of the cab?" and "What is the color of the woman's scarf?". Participants' performance of the watching movie clips tasks was measured by how well they could answer the questions about the video clips.

In the practice drive, the participants had to watch a practice video clip that helped them understand what types of questions would be asked in the experimental drive. During the experimental drive, the participants watched three movie clips with no events occurred. Then, the participants experienced two induced drifts that took place on straight lanes. The interval of these two induced drifts was approximately 8 minutes. They experienced one induced drift (a wind gust pushed the vehicle out of lane towards the shoulder) when they were driving with the non-driving task (watching video clips) and experienced the other induced drift while driving in absence of the non-driving task. In the automated driving condition, the induced drifts were accompanied with a simultaneous and unannounced (i.e., with no alarm) a LK system failure. The wind that induced the drift was 90 degrees to the direction of the vehicle movement with 64 mph wind speed. The order of the induced drifts with or without non-driving task was counterbalanced.

During the experiment, all participants completed the Complacency Potential Rating Scale (CPRS) (Singh et al., 1993a) to measure complacency towards the automation and the Interpersonal Trust Scale (ITS) (Rotter, 1967) to measure the level of interpersonal trust. Participants who used ACC and LK systems had two more surveys to measure their attitudes towards the LK system, which were Acceptance Scale (AS) and Trust Scale (TS) The acceptance scale was modified based on Van Der Laan et al. (1997). This scale was composed of nine questions. The trust scale was based on the trust questionnaire developed by Donmez et al. (2006). In addition to the two statements for trust measure used in Donmez et al. (2006), another statement that was also used to measure if drivers' prefer to use the LK system in the future after they experiencing the failure of the LK system. Three statements were used from the scale were "I trust the LK system", "The performance of the safety enhanced my driving", and "I prefer to use lane keeping on

Interstates or freeways”. All the surveys in this experiment were measured by a 5-point Likert-scale with anchors ranging from strongly disagree (1) to strongly agree (5).

As this study investigated drivers’ responses to the lane departure events, in addition to the reaction times, participants’ responses to the induced drifts were also quantified by the durations of lane departure and the maximum steering wheel angles which measured participants’ lateral control of the vehicles. The reaction times were defined as the time between the initiation of the induced drift and the moment the participant first adjusted the vehicles’ heading via moving the steering wheel. The larger the reaction times suggested the slower the participants reacted to the induced drifts. Durations of lane departure were the period of the vehicle that departed from its original lane. Participants with larger durations of lane departure were more likely to have longer exposure to the on-road/off-road hazards. The maximum steering wheel angles were the maximum absolute difference of the steering wheel angle between its initial direction and its direction throughout the induced drift. Participants with larger maximum steering wheel angles tend to respond the induced drift in a severer method. The significant level was set at 0.05 for the following analyses and all analyses were conducted in R x64 3.0.2.

Results

Effects of automation on non-driving task performance

Each participant’s level of engagement in the non-driving task was quantified by assessing if the participants answered the multiple-choice questions about each video clip correctly (there were two questions following each video clip, thus in total, there were eight questions.). Data were analyzed using a repeated measures binomial logistic regression model (using the *glmer* function in the *lme4* package of R). The response variable was a dummy variable to indicate whether the participants answer a certain question correctly (1=correct answer). The predicting variables were the question numbers (with Question 1 used as the reference question) and the level of automation (1=the level 2 automation condition). The inclusion of the question numbers was to account for the potential effects of differences in question difficulty. All of the participants answered questions 4 (“What is the animal on the projector?”) correctly, therefore, question 4 was not included in the model to avoid the singularity issue within the model. Additionally, participants were regarded as the random effect in the model. The odds ratio was 1.67 with 95% CI [1.66, 1.68] between participants in the automated driving condition and those in the manual driving condition to answer the questions correctly (Table 1).

Table 1. Repeated-measures binomial logistic regression model on the corrections of the answers

Random Effects					
Variable	Variance	S.D.			
Participants (intercept)	0.507	0.712			
Fixed Effects					
Variable	Estimate	S.D.	z value	p-value	Odds ratio
(Intercept)	1.895	0.002	774.0	<0.001	
Question 2	-0.656	0.002	-268.4	<0.001	0.518
Question 3	-1.471	0.002	-601.3	<0.001	0.230
Question 5	-1.469	0.002	-600.4	<0.001	0.230
Question 6	-0.514	0.002	-209.9	<0.001	0.598
Question 7	-2.054	0.002	-839.7	<0.001	0.128
Question 8	0.001	0.002	0.500	Ns*	
Higher level of automation	0.513	0.002	209.5	<0.001	1.667
Reduced log-likelihood (intercepts only)					-191.492 (df=2)
Log-likelihood at convergence					-175.529 (df=9)
χ^2 value					31.93 (df=7)

* ns represents that the factor is not significant

Effects of automation on non-driving task performance

Participants' glances were manually coded for each frame from the video record of the participants face by one researcher. As variances of participants' glances on the in-vehicle display were significantly different between the manual driving condition (SD=0.79 s) and the automated driving condition (SD=5.80 s; $F_{23, 23}$=0.018, p<0.01). Then the t test with unequal variance showed that the mean glance duration for participants in the manual driving condition (M= 1.25 s) were significantly shorter than the mean glance duration for the participants in the automated driving condition (M= 5.12 s; $t_{23.83}$=3.24, p<0.01).

Effects of automation and non-driving task on drivers' responses to safety critical events

The effects of the automation and non-driving task on driving responses to the induced drifts were assessed with respect to the reaction time, duration of lane departure, and maximum steering wheel angle. The data were analyzed using a mixed effects ANOVA with the between-subject factor of automation and the within-subject factor of non-driving task status. The sequence of the induced drifts was also considered into the models as an explanatory factor to account for the learning effects of the induced drifts.

Reaction time

Participants who used the ACC and LK systems (M=1.27 s, SD=0.61 s) had longer reaction time than those who manually driving the simulator (M=0.69 s, SD=0.30 s; $F_{1, 46}=28.48$, $p<0.01$). Reaction time was also significantly longer when the participants were watching the movie clips (M=1.13 s, SD=0.67 s) than when not watching the movie clips (M=0.84 s, SD=0.37 s; $F_{1, 46}=15.21$, $p<0.01$). Figure 11 shows the means of the reaction times with standard error bars across the factors of automation level and non-driving tasks. Additionally, the sequence of the induced drifts was one of the significant factors. The reaction time of the first induced drift (M=1.10 s, SD=0.66 s) was longer than the reaction time of the second induced drift (M=0.90 s, SD= 0.42 s; $F_{1, 46}=6.81$, $p<0.01$).

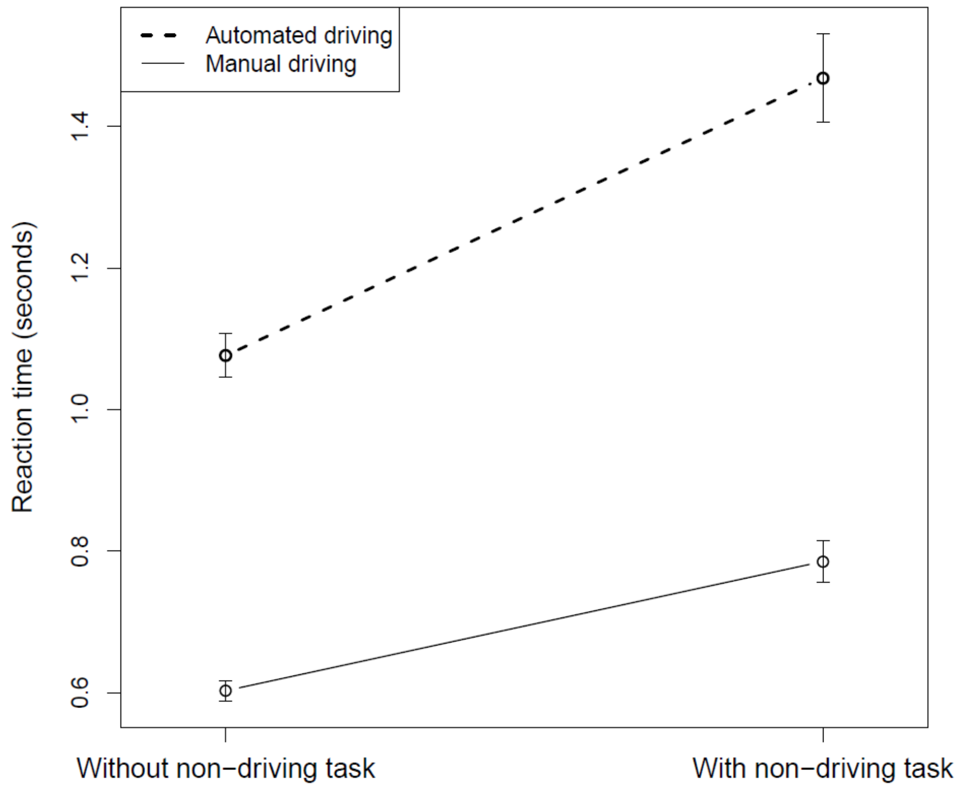


Figure 11. Reaction time (with standard error bars) for the with and without a non-driving task for the manually driving or the automated driving

Duration of Lane Departure

The automation condition ($F_{1, 46}$= 17.52, p<0.05) and the sequence of the induced drifts ($F_{1, 46}$=10.15, p<0.05) were significant factors in the ANONA table. Participants who used the ACC and LK systems (M=4.65 s, SD=4.11 s) had longer duration of lane departure than their counterparts who manually drove the simulator (M=2.07 s, SD= 1.67 s). The durations of lane departures during the first induced drift (M=2.39 s, SD=1.58 s) were significantly shorter than that during the second induced drift (M=4.33 s, SD=4.33 s). The means of the duration lane departure time with standard error bars across the factors of automation level and non-driving tasks are shown in Figure 12. For participants who manually drove the simulator, the paired t-test showed that driving in absence of the watching video clip task (M=1.48 s, SD=1.00 s) had a significantly shorter duration of lane departure than driving with non-driving task (M=2.65 s, SD=2.01 s; $t_{1, 23}=-2.57$. $p<0.05$).

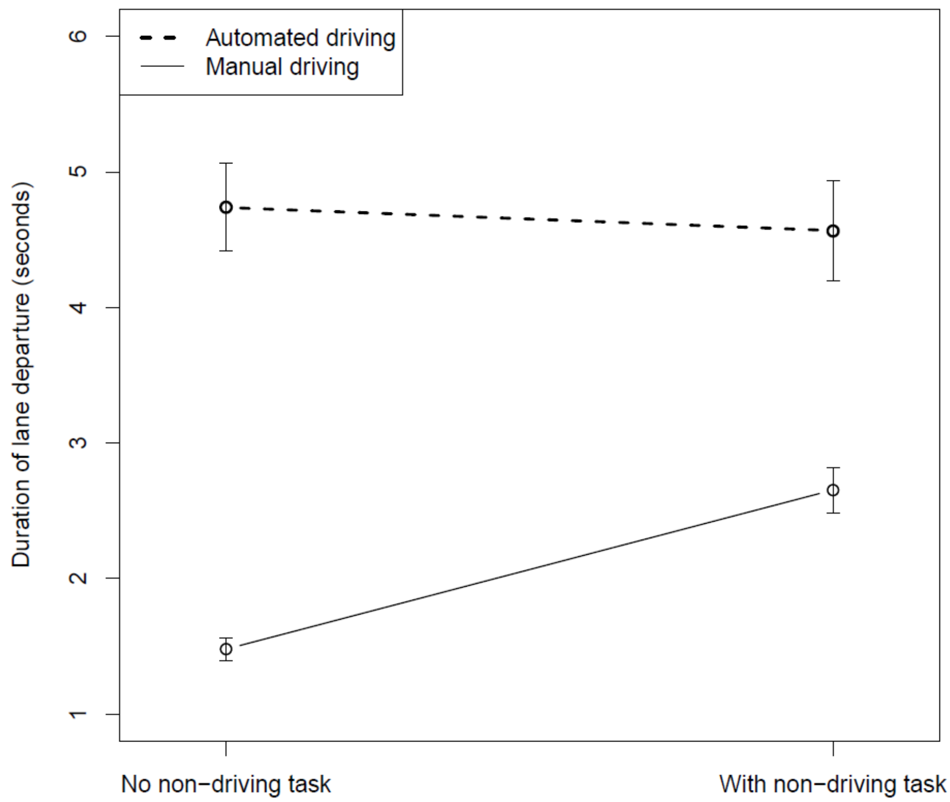


Figure 12. Lane departure time (with standard error bars) (with standard error bars) for the with and without a non-driving task for the manually driving or the automated driving

Maximum steering wheel angle

There was only one significant predictor of maximum steering wheel angle: the automation condition ($F_{1, 46}=16.50$, $p<0.01$). Participants with the ACC and LK systems engaged (M=10.93°, SD=3.48°) had larger maximum steering wheel angle than those manually driving the simulator (M=18.34°, SD=11.20°). The non-driving task status ($F_{1, 46}$=1.25, p=0.27) and the sequence of the induced drifts ($F_{1, 46}$=0.26, p=0.61) were not significant. Figure 12 shows the mean values of maximum steering wheel angle across the factors of levels of automation and non-driving task status. However, for participants who manually drove the simulator, a paired t-test showed that there was a significant difference between the mean maximum steering wheel angles for the driving with a non-driving task and driving without a non-driving task (mean difference=-1.44, t_{23}=-2.20, $p<0.05$).

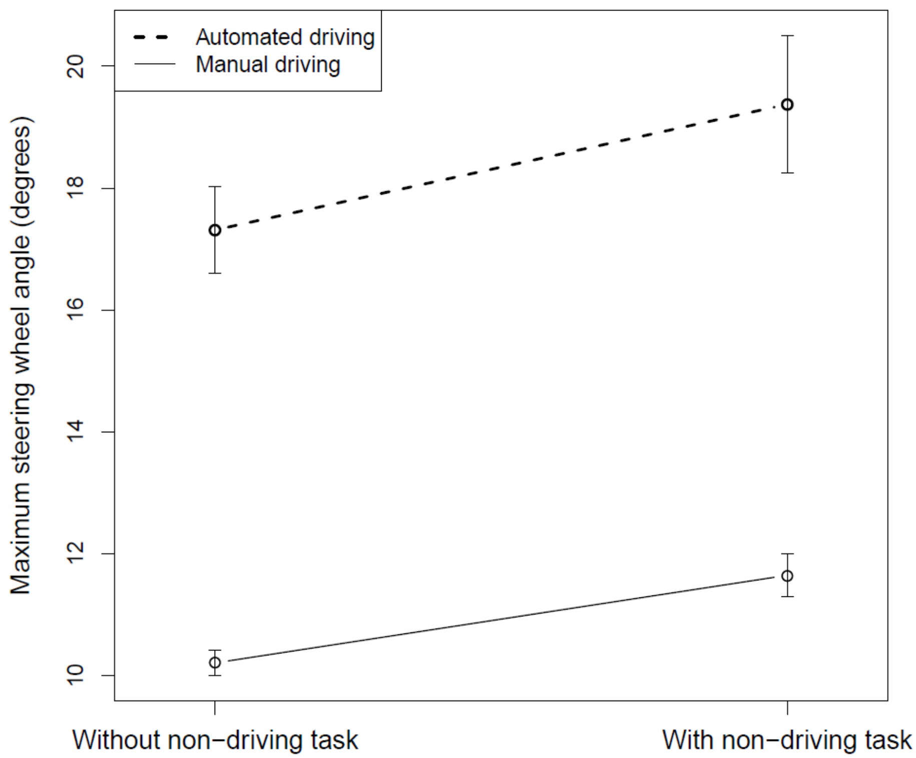


Figure 13. Maximum steering wheel angle (with standard error bars) (with standard error bars) for the with and without a non-driving task for the manually driving or the automated driving

Effects of the characteristics and attitudes towards automated systems on drivers' responses to safety critical events

Some of the questions of the surveys used in this study had positive and negative questions. The responses to negative questions were transformed to correspond to the positive questions. Only the questionnaires of the participants who used the ACC and LK systems were included in the analysis. The summary of the four questionnaires were shown in Table 2. The correlations between the participants' responses to the four questionnaires and their behaviors (reaction times, durations of lane departure, and maximum steering wheel angles) during the induced drifts with/without watching a movie clip were tested by the *rcorr* function in the *Hmisc* package of R. The results showed that the trust scale was significantly negatively correlated to the maximum steering wheel angles when the participants experienced the induced drift with watching the movie clip (r=-0.41, p=0.05). No other significant correlations were been found.

Table 2. Summary of the four questionnaires

Questionnaires	Possible Range	Real Range	Median	Mean(SD)
Complacency Potential Rating Scale	12-60	38-55	46.5	46.5 (4.24)
Interpersonal Trust Scale	25-125	57-82	69.5	70.04 (7.11)
Acceptance Scale	9-45	16-43	29.5	30.08 (7.07)
Trust Scale	3-15	14-Mar	7.5	8.13 (3.33)

Discussion

The main objective of this study was to evaluate the effects of the out-of-the-loop issue induced by the implementation of the in-vehicle automation (i.e., Level 2 automation) and drivers' engagement of the non-driving tasks on drivers' responses to the safety critical events with the failure of the in-vehicle automated systems. The present results indicated the workload for drivers in Level 2 automation vehicles were lower than those in L0 automation vehicles, as participants in the automated driving condition had a better performance of the non-driving tasks than those in the manual driving condition. Similarly, Young and Stanton (2002) has found that drivers using both the ACC and LK systems had the best non-driving task performance which indicated the least workload compared to those using only the ACC or driving the vehicles manually. The glance durations to the in-vehicle display also suggested that the workload of the drivers in the manual driving condition and the automated driving condition was different. Drivers driving with the ACC and LK systems had longer glance durations to the in-vehicle displays than drivers who manually operated the vehicle. Thus, drivers in the automated driving condition could exhibit less safe behaviors than that in the manual driving condition. In addition, as the variance of participants' mean glance durations on the in-vehicle display in the automated driving condition was much larger than that in the manual driving condition, it suggests that the individual differences in drivers' interactions with non-driving tasks may exist while drivers are in level 2 automation vehicles. Future research should consider the individual variance in level 2 automation vehicles.

Our study suggested that, regardless of the presence of the watching movie clip tasks, the engagement of the ACC and LK systems impaired drivers' responses to the lane departure events, with respect to the reaction times, durations of lane departure, and maximum steering wheel. Furthermore, our results also suggested that drivers' reaction times to the lane departure events would be even worse while they were distracted by the non-driving tasks in the automated driving condition. One study conducted by Merat et al. (2012) found that drivers' responses to the safety critical events were degraded when drivers were required to take control of the vehicles from the automation while involving in the non-driving tasks. However, they found that in the absence of the non-driving tasks, drivers' responses to the safety critical events were similar in the manually driving condition and driving with the ACC engaged. This inconsistency of drivers' responses to the safety critical events in the absence of the non-driving tasks in the highly automated vehicles may be because driving with only ACC engaged and driving with both ACC and LK engaged are two different levels of automated driving (level 1 versa level 2) . For example, it has been suggested that the use of ACC does not necessarily lower the levels of workload compared to the manual driving and drivers who used both the ACC and LK systems tend to have the least workload among driving manually, with ACC engaged, or with LK system engaged (Stanton & Young, 1998). The reduced workload caused by automation was associated with lowering vigilance, moving the drivers furthering away from the control loop, and lowering situation awareness (Woods, 1988; Endsley & Kiris, 1995; Stanton & Young, 1998; Sheridan, 2006). When driving with only ACC engaged, drivers have to control the lateral position of a vehicle, in which condition drivers are still within the vehicle control loop. However, when driving with both the ACC and LK systems engaged, drivers do not have to control the vehicle and can be out of the vehicle control loop when there is no hazard on the road. Thus, the behavioral consequences upon the failures of a DSS were worse when drivers were in level 2 automation vehicles than when they were in L1 automation vehicles. Driving with the ACC and LK systems engaged while distracted by watching DVD players could further worsen drivers' reaction times to the lane departure events with the failure of the LK system.

Our study did show that the durations of lane departure and maximum steering wheel angles were influenced by the non-driving tasks in the condition with no automation. However, the watching movie clip tasks did not have significant effects on the measures of durations of lane departure time and maximum steering wheel angles when drivers were driving with the ACC and LK systems engaged. It has been found that when using the ACC and LK systems, drivers may be more willing to be involved in non-driving tasks and engaged in risky behaviors (e.g., extended glances away from the forward roadway) compared to when they are driving with only the ACC engaged (Llaneras et al., 2013). This suggest that the reduced primary task demands associated with supervising the automation (compared to that of manual driving) may facilitate diverting more of the driver's attention away from the supervising automation tasks towards the non-driving task in level 2 automation vehicles, though there is no specific non-driving task. Thus, the effect sizes associated with the non-driving tasks may be smaller when drivers are using the ACC and LK systems compared to when drivers are manually driving the vehicle. In addition, there were two participants that were excluded from the analysis, as they failed to respond to the induced drift when they were watching a movie clip in the automated driving condition. Removing the non-response responses also reduces the effect size of the non-driving task on drivers' performance when drivers are using ACC and LK systems.

The results of the study also suggests that when watching a movie clip, drivers with better responses (smaller maximum steering wheel angle) to the safety critical events in level 2 automation vehicles tend to trust the system more. The results showed that drivers have a longer reaction time in the first drift than in the second drift. It may be related to the learning effects of the induced drifts. Operators' behaviors have been suggested to be worse during the first failure of automation (Molloy & Parasuraman, 1996; Bailey & Scerbo, 2007). After experiencing the first lane departure event with the failure of the LK system, participants in the automated driving condition might develop an expectation that the LK system might not work well all the time. This expectation then improved their responses during the failure of the LK system. Thus, it is necessary to instruct drivers about the limitations of the automated DSSs and help them develop a correct expectation on the functions of the automated DSSs. However, in terms of the durations of lane departure, drivers have shorter durations of lane departure in the first drift than in the second drift. Perhaps this was caused by the designs of the scenario. Although the vehicle was pushed to drift outside of its original lane during both the induced drifts, there was no other safety critical event that occurred during the events. Thus by experiencing the first induced drift, the participants might have responded more quickly to the second drift. However, as they expected no other safety critical events would happen, they did not have to counter the drift intensively, which resulted in a longer lane departure time. Further research needs to be done to determine whether drivers' experiences with safety critical events in level 2 automation vehicles improve drivers' performance when they are met with similar safety critical events.

There were several limitations associated with this study that need to be considered. First, participants' glance durations to the in-vehicle display were coded by the same researcher who conducted this experiment. Thus, the glance durations might be subjective and biased. However, the significant results ($p<0.01$) of the t test between the glance durations of the participants in the manual driving condition and in the automated driving condition still exists due to the large differences of those glance durations. Second, the participants of this study were younger drivers aged between 18 and 25 years-old. Younger drivers are more likely to accept new technologies and have improved performance when using these technologies (Czaja & Lee, 2007). However, younger drivers tend to be less experienced drivers and have higher likelihood to engage in risky behaviors (Smith, Meshkati, & Robertson, 1993; Islam & Mannering, 2006). Young and Stanton (2000) have found that compared to experienced drivers, inexperienced drivers have longer reaction times to the malfunction of the ACC when they used the ACC and LK systems. For future work, it will be valuable to determine the impact of automation and non-driving tasks on the performance of drivers from different age groups and experience levels. The scenarios of the current study were rural interstate freeways with low traffic density. It is also important to understand drivers' interactions with level 2 automation vehicles in urban area with a high traffic density. In addition, the non-driving task in this study was watching movie clips each of which was between 40 s' to 1 min's long. When drivers were watching a real hours' long movie, they may be more likely to be engaged in the movies and had even worse responses to the lane departure events. Furthermore, there are other in-vehicle sources of distractions including the cell phones and the navigation systems. Future work should exam the effects of these distraction sources on drivers' interactions with level 2 automation vehicles. Additionally, with ACC and LK system engaged, the drivers' task was fundamentally different from the driving tasks when drivers were manually driving the vehicle. In level 2 automation vehicles, the drivers' role has been altered from a driver to an automation system supervisor. Thus, in level 2 automation vehicles, some measures of drivers' performance may not be valid or meaningful to compare manual driving to supervisory automation. For example, the mean of speed and variance of speed, which can be used to reflect drivers' longitudinal control of the vehicle, is not a good measure of drivers' performance in highly automated driving condition as the automation would control the speed. In this study, when there was an induced drift, all participants in the manual driving condition responded to the event by moving the steering wheel to counter the drift accompanied by reducing the speed. However, none of the participants in the automated driving condition turned off ACC and thus maintained a constant speed at 65 mph. This results in a difference in response style towards a lane departure event between the two groups of the participants. This also results in a positive nonlinear relationship between lane departure distance and duration of lane departure due to speed variability.

Conclusion

To conclude, the results of our study suggest that in level 2 automation vehicles, drivers' responses to the safety critical events are impaired, regardless of the presence of the non-driving tasks. Their responses were even worse when drivers' attention was diverted toward a demanding non-driving task (e.g., watching movies) in level 2 automation vehicles. Therefore, it is vital for drivers not to be involved into a non-driving task that requires drivers' extended glances off the forward road, as they are easily to develop the out-of-the-loop problem associated with automation. For example, if the level 2 automation vehicles detect drivers' mean glances off the roadway are longer than the safety level in a certain period, the vehicles will respond to drivers' unsafe behaviors, such as warning the drivers or even stop working. Alternatively, while drivers are watching the in-vehicle DVD players, the information of the status of the automation and around traffic is also presented on the in-vehicle display. Overall, with a better understanding of behavioral consequences of automation complacence, it may be possible for policy makers and manufactures to develop solutions to drivers' degraded behaviors during the failures of DSSs.

CHAPTER 5: ASSESSING DRIVERS' RESPONSES TO THE LANE DEPARTURE EVENTS FOLLOWING AUTOMATED DRIVER SUPPORT SYSTEM FAILURES WITH AN AUDIBLE WARNING

This chapter describes the design of the experiment to address the third aim of the dissertation. An audible warning is raised to alert drivers to a lane departure event. The objective of this experiment is to investigate the effects of an audible alert (a warning) to the failure of the LK system (simulated as an induced drift) on drivers' responses during the moment that the LK system fails when drivers are doing a non-driving task (watching video clips) in level 2 automation vehicles.

Methods

Participants

Fifty-five native English speakers with a valid U.S drivers' license participated in this study. Seven participants were excluded from the analysis; one of them failed to pass the color vision test and six of them experienced equipment or experimental errors. Finally, the data of forty-eight participants (range 18-25 years old, M=20.07, SD=1.60, 24 males and 24 females) from the current experiment combined with the data provided by the forty-eight participants (range 18-25 years, M=21.17, SD=1.91, 24 males and 24 females) from the previous experiment of Chapter 4 were used for the analysis.

Apparatus

The study was conducted using a National Advanced Driving Simulator (NADS) MinSim driving simulator. The detailed description of a NADS MinSim can be found in Xiong et al. (2012). A 7-inch LCD monitor was used as an in-vehicle display and was attached to the right of the dashboard display. The center of the display was approximately 25 cm from the center of the dashboard display and 3 cm from the top of the dashboard display. The angle of the in-vehicle display could be adjusted by the participants as needed.

Procedures

Upon arrival, participants were given a brief introduction to this experiment and signed an informed consent form approved by the Institutional Review Board (IRB) at Clemson University (IRB# 2014-398). Then, participants' color vision was assessed using Ishihara color blindness test plates. After passing the test, the participants were given two questionnaires: the Potential Complacency Rating Scale (Singh et al., 1993a) and the Interpersonal Trust Scale (Rotter, 1967). Before the experimental drive which lasted about 30 minutes, participants completed one 7 minutes' practice drive. Participants were asked to set the speed at 65 mph (104 kmh) in all drives. After the experimental drive, participants who used the ACC and LK systems completed two more surveys: the acceptance scale on the LK system modified based on Van Der Laan et al. (1997) and trust scale on the LK system modified based on Donmez et al. (2006). The procedure for this experiment was identical to the procedure of Chapter 4.

Experiment design

This experiment was identical to Chapter 4 and was a 2×2 repeated measures design with two automation conditions (manual driving (level 0 automation) and driving with the ACC and LK system engaged (level 2 automation)) as a between-subjects factor and two non-driving task status (driving with non-driving task and driving without non-driving task) as a within-subjects factor. The only difference between the current experiment and the previous experiment was that an audible warning was incorporated in the scenario. A series of two four-beep lane departure warnings was raised at the moment when the LK system failed. Thus, the prediction time of the warning for the potential lane departure event following the failure of the LK system was approximate 1.48 s. The prediction time is defined as the time duration between the moment when the vehicle starts drifting and the moment when that vehicle crosses the lane borders. An in-vehicle display was attached at the right side of the dashboard. Participants were asked to watch three movie clips and each movie clip was followed by two multiple choice questions. Each multiple choice question was related to the visual or audio content of the movie clips. Therefore, the participants of the current experiment had exact same experiences as the participants of the previous experiment before encountering the lane departure events.

After watching three movie clips, the participants came across two potential lane departure events. Both lane departure events were induced by a wind gust that pushed the vehicle towards the shoulders of the lane. In the automated driving condition, the induced drifts were accompanied with a LK system failure. The wind that induced the drifts was orthogonal (i.e., 90 degrees) to the direction of the vehicle movement with a 64 mph (102 kmh) wind speed. When driving the simulator, the participants encountered one drift while they were engaged in the non-driving task (i.e., watching video clips) and the other one while they were not engaged in the non-driving task. The sequence of the induced drifts with or without non-driving task was counterbalanced.

Participants' responses to the induced drifts were measured by their reaction time, duration of lane departure, and maximum steering wheel angle. The reaction time was defined as the time between the initiation of the induced drift and the moment the participant correctively operated the steering wheel to counter the effects of the induced drift. Duration of lane departure was the time period of the vehicle during which it departed from its original lane (i.e., the right lane). The maximum steering wheel angle was the maximum absolute difference of the initial position of the steering wheel and its position throughout the induced drift.

Results

The data collected from this study and the previous study were combined and used for analysis. As users' level of potential automation complacency and interpersonal trust may influence their interactions with automation (Singh et al., 1993b; Ross & LaCroix, 1996; Lewandowsky et al., 2000), the Complacency Potential Rating Scale (CRPS) and Interpersonal Trust Scale (ITS) were compared between the participants from the two studies. No significant difference of the CRPS (t_{94}=-0.21, p=0.84) and the ITS (t_{94}=-0.77, p=0.44) were found between the participants from two studies. Thus, the participants of the two experiments do not differ in age, sex, and attitudes towards automation. Finally, this combined dataset was a 2×2×2 repeated measures design, with two between-subject factors of automation conditions and warning conditions and one within-subject factor of non-driving task status. The sequence of the induced drifts was also included into the models as an explanatory factor to determine if the learning effects of the induced drifts need to be accounted for. Participants were separate into two groups based on their automation conditions (i.e., the manual driving condition and the automated driving condition) and analyses were conducted to further examine differences in each condition. The significant level was set at 0.05 for the following analyses and all analyses were conducted in R x64 3.0.2.

Reaction time

Participants who experienced the induced drifts with an audible warning had significantly shorter reaction time (M=0.81 s, SD=0.41 s) than their counterparts who were without a warning (M=1.00 s, SD=0.56 s; $F_{1, 93}=8.03$, $p<0.01$). The reaction time was also significantly longer for participants who used the ACC and LK systems (M=1.16 s, SD=0.54 s) than participants who manually drove the simulator (M=0.65 s, SD=0.27 s; $F_{1, 93}=59.45$, $p<0.01$). Figure 14 shows the means of the reaction times with standard error bars across the factors of automation condition, non-driving tasks, and warning conditions. When engaging in the non-driving task, participants had significantly longer reaction time (M=1.00 s, SD=0.58 s) than when not engaging in the non-driving tasks (M=0.81 s, SD=0.37 s; $F_{1, 94}=16.43$, $p<0.01$). The sequence of the induced drifts also significantly influenced participants' reaction time ($F_{1, 94}=14.39$, $p<0.01$). The reaction time of the first induced drift (M=1.00 s, SD= 0.58 s) was significantly longer than that of the second induced drift (M=0.81 s, SD= 0.38 s) for all participants.

Additionally, when only considering the participants in the automated driving condition (the level 2 automation condition), the interaction between non-driving status and warning conditions were also significant in predicting the reaction time ($F_{1, 45}$=4.92, p=0.03). The difference of the reaction time between the two warning conditions when participants were not engaged in a non-driving task (difference=0.08 seconds) was significantly smaller than the difference when participants were engaged in a non-driving task (difference=0.30 seconds). No additional significant difference was found when considering the participants in the manual driving condition.

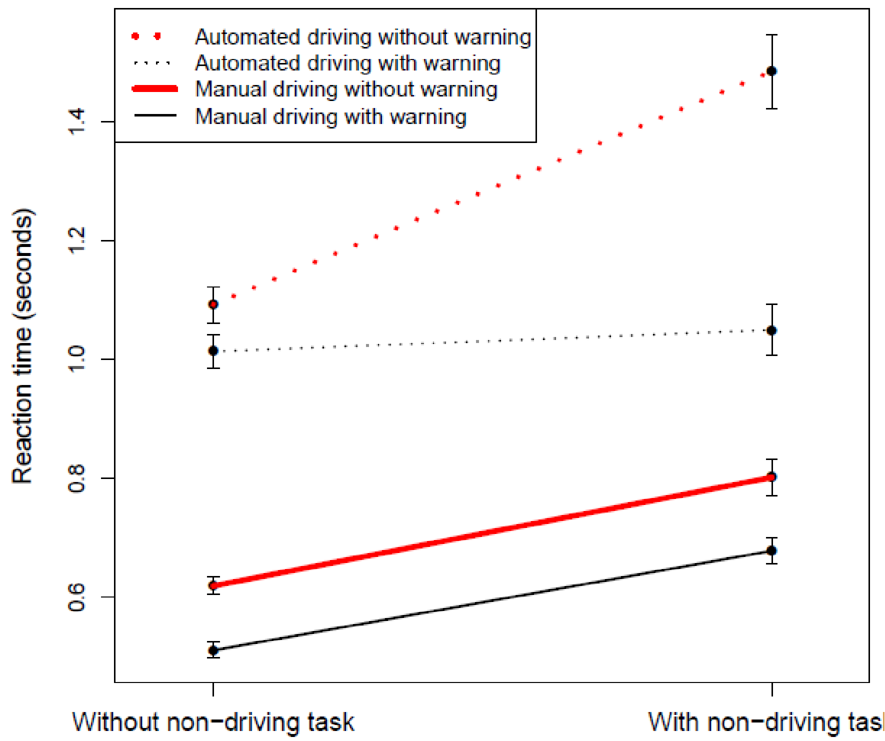


Figure 14. Reaction time (with standard error bars) across automation conditions, non-driving task status, and warning conditions

Duration of Lane Departure

The duration of lane departure was significantly longer for participants in automated driving condition (M=4.45 s, SD=3.71 s) than those in manual driving condition (M=1.96 s, SD=2.60 s; $F_{1, 93}=29.98$, $p<0.01$). The main effects of the non-driving task ($F_{1, 93}=0.03$, $p=0.85$) and warning conditions ($F_{1, 93}=0.46$, $p=0.50$) were not significant in predicting the duration of lane departure. However, when only participants in the manual driving condition were considered, the interaction between the non-driving status and warning conditions were significant ($F_{1, 46}=4.35$, $p=0.04$). In the manual driving condition, when not being engaged in non-driving task, participants with lane departure warnings presented had longer lane departures (M=2.36 s, SD=4.58 s) than their counterparts without lane departure warnings presented (M=1.48 s, SD=1.01 s). When engaged in a non-driving task, participants with a lane departure warning had a shorter duration of lane departure (M=1.33 s, SD=0.83 s) than their counterparts without a lane departure warning (M=2.65 s, SD=2.01 s). No additional significance was found when only the participants in the automated driving condition were considered. Figure 15 shows the means of the durations of the lane departure with standard error bars across the factors of automation level, non-driving tasks, and warning conditions.

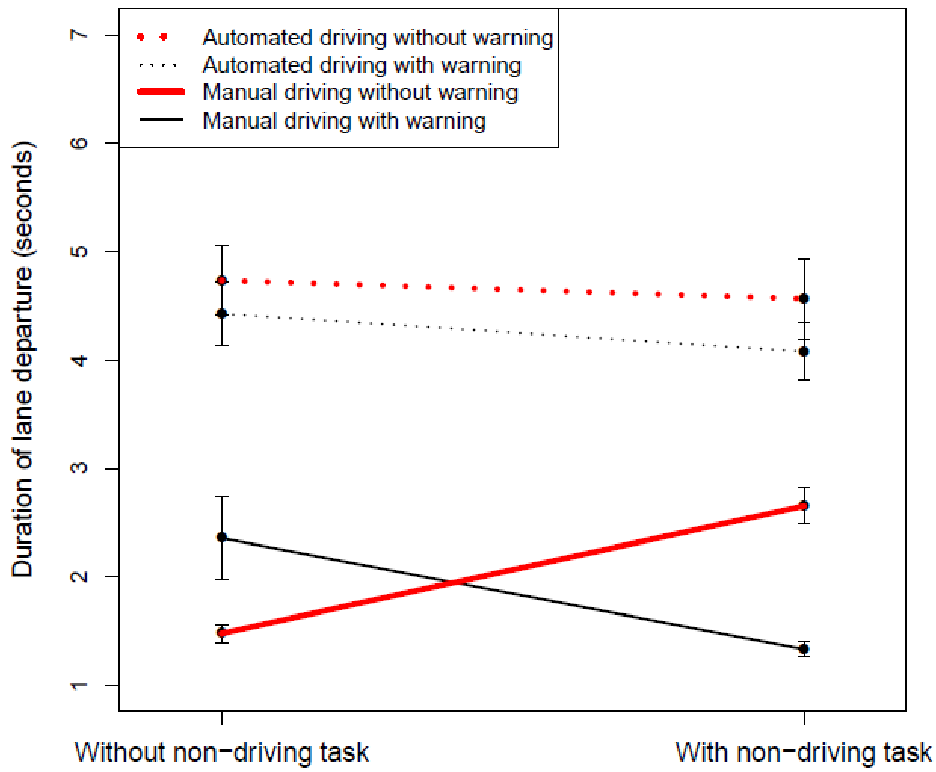


Figure 15. Duration of lane departure (with standard error bars) across automation conditions, non-driving task status, and warning conditions

Maximum steering wheel angle

The main effects of the automation condition ($F_{1, 92}$=28.43, p<0.01) and warning conditions ($F_{1, 92}$=5.48, p=0.02) and their interaction ($F_{1, 92}$=4.20, p=0.04) were significant in predicting the maximum steering wheel angle when participants experienced an induced drift. Participants in the automated driving condition without a warning had the largest maximum steering wheel angle (M=18.34°, SD=11.20°) compared to their counterparts in the automated driving condition with a warning (M=13.93°, SD=5.05°), those who manually drove without a warning (M=10.93°, SD=3.48°), and those who manually drove with a warning (M=10.64°, SD=3.03°). Figure

16 shows the means of the maximum steering wheel angle with standard error bars across the factors of automation level, non-driving tasks, and warning conditions. When only the participants in the manual driving condition were considered, the interaction of non-driving task and warning ($F_{1, 46}$=6.26, p=0.02) was the only significant factor in predicting the maximum steering wheel angle. When there was no non-driving task, participants who experienced an induced drift without a warning have a smaller maximum steering wheel angle (M=10.21°, SD=2.44°) than those with a warning (M=11.17°, SD=3.23°). However, when participants were engaged in the non-driving task, the maximum steering wheel angle for participants experiencing an induced drift without a warning (M=11.65°, SD=4.21°) was larger than those experiencing an induced drift with a warning (M=10.10°, SD=2.79°).

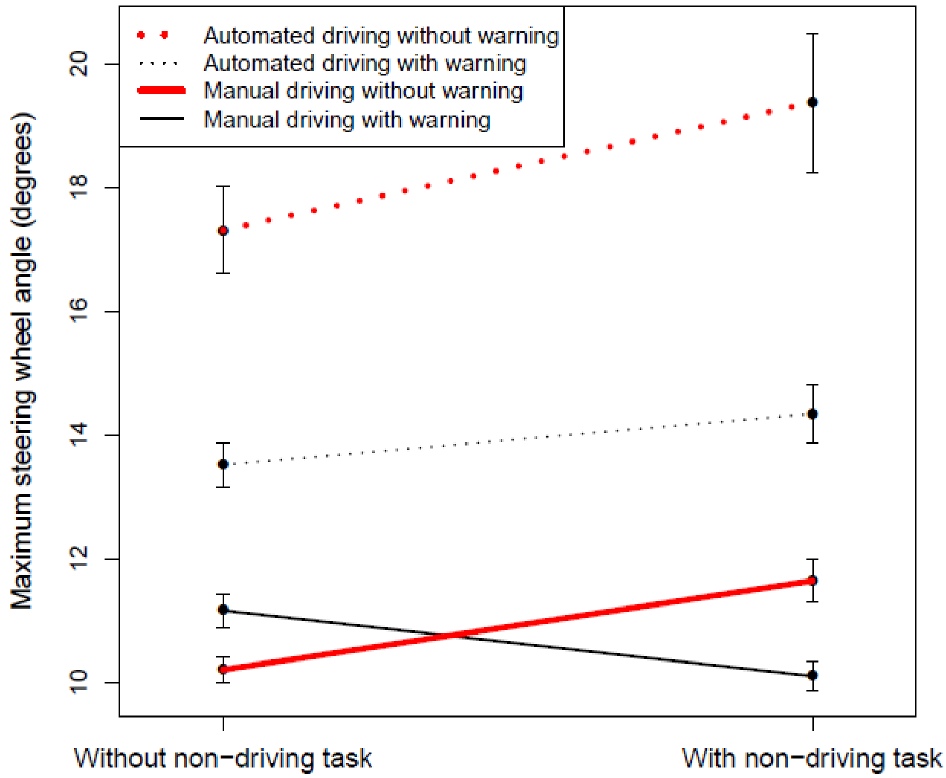


Figure 16. Maximum steering wheel angle (with standard error bars) across automation conditions, non-driving task status, and warning conditions

Acceptance scale and trust scale

The results of previous studies have showed that users' interaction with automation positively corresponds to their acceptance and trust on that system (Dillon & Norcio, 1997; Dzindolet et al., 2003; Madhavan, Wiegmann, & Lacson, 2006). Specifically, it has been showed in Chapter 4 that drivers with better responses to the failure of the LK systems had a higher trust scale. As participants in the automated driving condition who experienced the induced drifts with a warning had performed better with respect to significantly shorter reaction time and smaller maximum steering wheel angle than those without a warning presented, it was hypothesized the acceptance and trust scales of participants experiencing the induced drift with a warning presented were higher than those without a warning presented. Thus acceptance scale and trust scale were compared by using one-sided t-tests. Participants who experienced the induced drifts with a warning had significantly larger trust scale ($M=9.83$, $SD=2.84$) than those who experienced the induced drifts without a warning ($M=8.13$, $SD=3.33$; $t_{46}=1.91$, $p=0.03$). However, the difference of the acceptance scale between the participants experiencing the induced drifts with a warning or without a warning was not significant.

Discussion

The purpose of this study was to evaluate the effects of lane departure warnings on drivers' responses to potential lane departure events (which were simulated by induced drifts accompanied with a LK system failure) when drivers were supervising level 2 automation vehicles. This study also sought to determine if the effects of an audible warning to lane departure events were consistent between manual driving conditions and semi-autonomous driving conditions. Unsurprisingly, the current results suggest that drivers in the level 2 automation condition tend to have longer reaction times, larger lane departure times, and larger maximum steering wheel angles compared to those who are driving manually. Similarly, many previous studies have identified that highly automated vehicles impair drivers' behaviors when there are safety critical events (Desmond et al., 1998; Young & Stanton, 2000; Merat et al., 2012). Additionally, the non-driving task status and sequence of the induced drifts had a significant effect on drivers' reaction time to the induced drifts across all the driving conditions. Drivers engaged in a non-driving task have a longer reaction time than being not engaged in a non-driving task. It has been shown in numerous studies that distracted driving degrades drivers' driving performance and increases drivers' responses time to safety critical events (Lam, 2002; Sheridan, 2004; Bunn et al., 2005; Donmez et al., 2006; Kass et al., 2007; Young et al., 2007; Koppel et al., 2011; Beanland et al., 2013). Furthermore drivers in level 2 automation vehicles more likely to be engaged in non-driving tasks (Merat et al., 2012; Llaneras et al., 2013).

The reaction time and maximum steering wheel angle were significantly shorter for drivers with a warning to alert the induced drifts than those without a warning across the two automation conditions. It indicates that an audible warning helps drivers in level 2 automation vehicles recover from lane departure events following the failure of the LK system and also improve the responses of drivers in level 0 automation vehicles to the lane departure events. As suggested by Norman (1990) and Sarter and Woods (1995), in order to attract operators' attention to state changes efficiently, an effective feedback of the automation functioning should be given to the human operators. Thus, an audible warning may draw drivers' attention to lane departure events drawn quicker than when there is no warning present and improve drivers' responses to the safety critical events. The significant interaction between the non-driving task status and warning conditions on the reaction time of drivers in level 2 automation vehicles suggests that warnings assist drivers in automated driving conditions more when they are engaged in a non-driving task, compared to when they are not engaged in a non-driving task. This interaction may also indicate that when engaged in non-driving tasks, the effects of lane departure warnings on improving drivers' reaction time may be more pronounced in level 2 automation vehicles than in level 0 automation vehicles. The results indicate that an audible warning may draw drivers' back to the control-loop of level 2 automation vehicles more quickly than before when only the "on/off" status of the ACC and LK systems are represented on the dashboard display. However, though a warning with a 1.48 s prediction time helps driver recover from the potential lane departure events in the level 2 automation condition, it did not decrease drivers' reaction time and maximum steering wheel angle to the extend where these values were similar to those in the level 0 automation condition. Thus, this may suggest the prediction time of the warning to lane departure events in semi-autonomous vehicles has to be longer than that in manually driving vehicles. This may also suggest that only using an audible warning is not sufficient to assist drivers in level 2 automation vehicles fully recover from the lane departure events as their counterparts do in manual driving conditions. In other words, drawing drivers' back to the vehicle control-loop quickly may not be as good as remaining drivers in the vehicle control-loop.

Unlike the positive effects the lane departure warnings have on the responses of drivers in automated driving conditions, an audible warning to the induced drift did not always improve the responses of drivers in the manual driving condition (the level 0 automation condition). When only participants in the manual driving condition were considered, the significant interaction of the non-driving task status and warning conditions on drivers' duration of lane departure and maximum steering wheel angle (the "X" shape in Figure 2 and 3) indicates that when drivers are in level 0 automation vehicles without a non-driving task, lane departure warnings increase drivers' duration of lane departure and maximum steering wheel angle; whereas when drivers are manually driving the vehicle with a non-driving task, lane departure warnings decrease drivers' duration of lane departure and maximum steering wheel angle. It has been found that a warning given to drivers the moment before they normally respond to an event could be regarded as a nuisance alarm, and thereby could reduce the acceptance of the system (Pierowicz et al., 2000). When drivers in level 0 automation vehicles are not engaged in a specific non-driving task, a warning may be regarded as a nuisance warning and provide an additional distraction to drivers who are about to respond to the lane departure event. This may result in larger duration of lane departure and maximum steering wheel angle compared to those drivers without a lane departure warning. However, when drivers in level 0 automation vehicles are distracted, a warning may assist them in responding to the lane departure event with smaller duration of lane departure and smaller maximum steering wheel angle. Many previous studies have identified the positive effects of warnings on drivers' responses to lane departure events when drivers are drowsy or distracted (Batavia, 1999; Rimini-Doering et al., 2005; Kozak et al., 2006). Therefore, the value of the warning may only be realized when drivers in manual driving conditions are engaged in a non-driving task.

For drivers with both the ACC and LK systems engaged, a warning following the failure of the LK system increases their trust on the LK system compared to those without a warning. It has been suggested that the lack of transparency or feedback of automation activities is closely related to users' loss of trust (Norman, 1990). Providing a warning to indicate the failure of the LK system improves the feedback of automation activities and results in higher trust on the LK system.

There are several limitations related to the current study. The data used for this chapter were from two experiments (i.e., two blocks). Participants in one block experienced the induced drifts without warning and participants in the other block experienced the induced drifts with warnings. Thus, block effects that confound the effects of the lane departure warnings on participants' responses to the induced drifts. However, the participants from these two studies did not differ in age, sex, attitudes toward automation, and experimental experience prior to the induced drifts. The only difference between these two experiments is that in experiment 3 when participants encountered the induced drifts, an audible warning was raised simultaneously, compared to experiment 2. In addition, this study only evaluated the effects of an audible warning as a discrete feedback of automation on drawing drivers back to the vehicle control-loop and on drivers' responses to lane departure events caused by the LK system failure. Some previous studies have evaluated the effects of other warning modalities (e.g., visual, haptic, and the combinations) on drivers' responses to forward collisions when they are using the ACC (Lee et al., 2006; Seppelt & Lee, 2007). Future research should estimate if a continuous feedback of automation activities or different warning modalities would help drivers remain in the vehicle control-loop and improve drivers' responses to safety critical events. Additionally, the participants of these studies were younger drivers (i.e., 18 to 25 years-old) so it will be necessary for future researchers to determine if the results drawn from younger drivers can be generalized to other age groups.

Conclusion

An audible lane departure warning improves drivers' responses to lane departure events in both level 0 and level 2 automation vehicles when drivers are distracted and engaged in non-driving tasks. This effect is more pronounced for drivers in level 2 automation vehicles, with respect to the reaction time. An audible warning with 1.48 s prediction time does not improve drivers' responses to the degree where they can respond to the potential lane departure events as efficient as their counterparts in the manual driving condition. The prediction time of lane departure warnings which is fit for the manual driving condition may have to be longer when drivers are supervising level 2 automation vehicles. It may also suggest that only audible warnings that could draw drivers' back to the vehicle control-loop more quickly may not be enough to solve the out-of-the-loop problem caused by automation. When drivers are not engaged in non-driving tasks, the effects of the lane departure warnings on drivers who are manually driving the vehicles or supervising the semi-autonomous vehicles without non-driving tasks are different. An audible warning positively influences drivers' responses to lane departure events in semi-autonomous vehicles regardless if there is a non-driving task or not. However, when drivers in the manual driving condition are not engaged in non-driving task and concentrating on the driving task, a lane departure warning may be regarded as a nuisance alarm and an additional source of distraction, which results in a larger duration of lane departure and maximum steering wheel angle. Thus, the effects of audible warnings with a same predication time are not consistent between the non-driving task status and the automation conditions. This may require the prediction time of lane departure warnings should vary based on drivers' attention and the automation level of the vehicles. By assessing and comparing the effects that a warning has on drivers' responses to the lane departure events (which is accompanied with the failure of the LK system) in manual and automated driving conditions, this study has added our understandings of how drivers' behavior differs between with level 0 automation vehicles and level 1 automation vehicles.

CHAPTER 6: CONCLUSIONS

The overall objective of this dissertation was to develop a better understanding of how semi-autonomous vehicles (level 2 automation vehicles) and non-driving tasks influence drivers' responses to the failures of a semi-autonomous vehicle component. In other words, this dissertation aimed to understand drivers' behaviors in the status transition from the semi-autonomous driving condition (the level 2 automation condition) shown in Figure 17 (b) to the lower levels of automated driving conditions (the level 0 or 1 automation conditions) shown in Figure 17 (a), when some driving support systems fail. The arrows 1, 2, and 3 represent the transitions from the lower levels of automation conditions to higher levels of automation conditions when drivers engage more automated DSSs. For example, arrow 1 stands for the transition from the level 0 or level 1 automation conditions to the level 2 automation condition when drivers engage both the ACC and LK systems. The arrows 4, 5, and 6 represent the transitions from the higher levels of automation conditions to the lower levels of automation conditions when some (or all) of the automated DSSs fail or drivers disengage some (or all) of the automated DSSs. Data from a driving simulator and surveys were used to evaluate the effects of automation levels, drivers' personalities and attitudes towards automation, non-driving tasks (watching movie clips), and audible warnings on their responses to the failures of the lane keep (LK) system.

Insights into the effect of automation levels on drivers' operating behaviors and drivers' responses to the failure of the LK system have been found in Experiments 1 and

2 (i.e., Chapter 3 and 4). The results of Chapter 4 have shown that when drivers are supervising the function of the automated driving support systems (DSSs), they are more likely to be engaged in a non-driving task and have longer glances off the forward road, compared to those who manually drive the vehicles. Drivers in level 2 automation vehicles could be more likely to be engaged in non-driving tasks, as the driving workload in automated driving conditions tends to be much lower than in the manual driving condition (Stanton & Young, 1998; Rudin-Brown & Parker, 2004). When the LK system fails, drivers in level 2 automation vehicles (with both the ACC and LK systems engaged) tended to have less safe (worse) responses (e.g., larger maximum lane deviation or larger maximum steering wheel angle), compared to their counterparts who were in level 0 automation vehicles (manually drove the vehicles) or in level 1 automation vehicles (drove a vehicle with only the LK system engaged). This suggests that drivers using high level automation could have less safe responses in the transition from the level 2 automation condition shown in Figure 17 (b) to the lower levels of automation conditions shown in Figure 17 (arrow 4). When the LK system fails on a curvy road, drivers respond worse than when the LK system (e.g., larger maximum steering wheel angle) fails on a straight road. Many studies have identified that the highly automated driving degrades drivers' behaviors when reclaiming control of the vehicle from automation during safety critical events (Stanton et al., 1997; Stanton & Young, 1998; Saffarian et al., 2012). In addition, non-driving tasks amplify the impairment of drivers' responses to a safety critical event in the transition shown by arrow 4 in Figure 17.

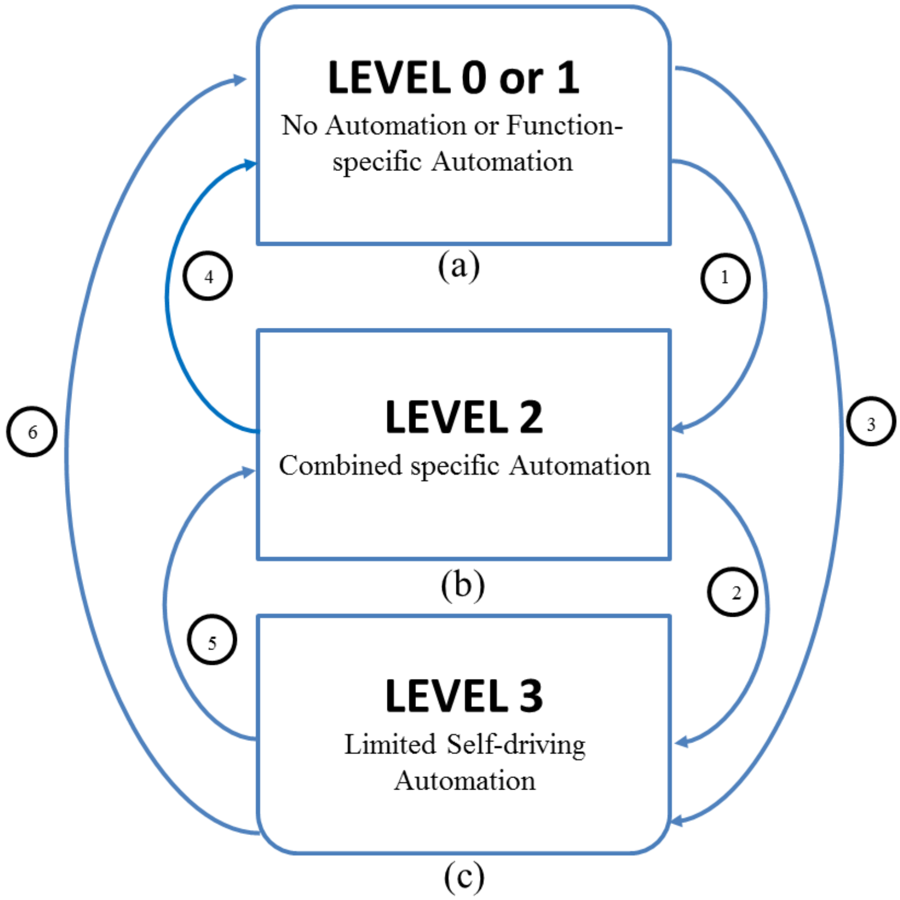


Figure 17. The transitions between each levels of automation (a) Level 0 or 1 automation; (b) Level 2 automation; (c) Level 3 automation

Audible warnings with a 1.48 s prediction time to alert drivers of a potential lane departure event improve drivers' responses to lane departure events in both level 0 and level 2 automation vehicles when drivers are engaged in a non-driving task. The effects of audible warnings are more pronounced when drivers are engaged in non-driving tasks in semi-autonomous vehicles (level 2 automation vehicles). However, the reaction times, durations of lane departure time, and maximum steering wheel angles of drivers in automated driving condition with a warning are still larger than those in manual driving conditions. This suggests that using audible warnings as discrete feedback for automation activities may draw drivers' attention back to the control loop more quickly but may not be sufficient to solve the out-of-the-loop problem associated with automation. In other words, an audible warning improves drivers' responses in the transition period from level 2 automation vehicles shown in Figure 17 (b) to the lower levels automation vehicles shown in Figure 17 (a) but could not keep drivers fully within the vehicle control loop. Additionally, the effects that lane departure warnings have on drivers' behaviors are not consistent between level 0 and level 2 automation vehicles. An audible warning positively influences drivers' responses to lane departure events in semi-autonomous vehicles regardless of the presence of a non-driving task. However, when drivers in the manual driving condition are not engaged in a non-driving task, a lane departure warning may be regarded as a nuisance alarm and an additional source of distraction. Thus, the effects of audible warnings with a same predication time are not consistent between the non-driving task status and the automation conditions. This may require that the prediction time of lane departure warnings vary based on drivers' distraction and the automation levels of the vehicles.

Drivers' level of interpersonal trust may affect their responses to the failure of the LK system. This relationship was supported by the Experiment 1 results, but it was not significant in either Experiment 2 or 3. As such, drivers with the higher level of interpersonal trust react to the transition from the driving condition shown in Figure 17 (b) to that shown in Figure 17 (a) (the arrow 4) in a severer method when the LK system fails (i.e., larger maximum lane deviation). In addition, drivers with better responses to the failure of the LK system were shown to be more likely to trust the LK system as a driving support system. Furthermore, with a warning present to indicate the failure of the LK system, drivers trust the LK system more than without a warning.

Broader impacts and intellectual merit

The results of the research further our understanding of drivers' behaviors in the status transition from the level 2 automation condition to the lower levels of automation conditions when some components of semi-autonomous vehicles fail. With a better understanding of drivers' interactions with in-vehicle automation and how drivers respond to automation failures, it is possible to generate recommendations for system designs that take the human operator's trust, the driver's situational awareness, and the drivers perception of the system failures into consideration. For example, the results suggest that drivers in semi-autonomous vehicles are more engaged in non-driving tasks and their glances tend to be much longer than two seconds. Previous research suggests glancing away from the roadway for more than two seconds doubles the risk of crash (Wierwille, 1993; Klauer et al., 2006). Thus, this suggests that drivers in highly automated vehicles may have to be reminded if they have glanced away from the roadway for long periods of time. In addition to long glances away from the roadway, some of the participants in the level 2 automation condition exhibited drowsy/ fatigue symptoms and one participant fell asleep during Experiment 1. It is important to examine the methods; such as alerts to wake up fatigued/sleepy drivers so that drivers remain attentive while driving with automated DSSs engaged.

It is also necessary to determine how to keep drivers in the control loop regardless of the level of automation in order to ensure that drivers' vigilance remains at a level that encourages safety and utilize the most appropriate supervisory control strategies. Though an audible warning as a type of feedback of automation activities assists drivers in recovering from the failures of semi-autonomous vehicle components, it may just draw drivers back to the control loop more quickly but not solve the out-of-the-loop problem brought on by highly automated driving. This suggests that an additional continuous feedback of automation may help drivers remain in the control loop. Furthermore, the results could help manufacturers offer improved safety guidelines for the system use of the ACC and LK systems, such as informing their users about the limitations of these systems. This study also provides support for future research related to fully autonomous vehicles (level 3 automation vehicles) which is relevant to what technology and automotive manufacturers are currently developing and testing.

Direction of future work

One of the conclusions of this dissertation is that younger drivers using higher levels of automation may perform worse when one subsystem fails. Many studies have suggested that physiological, psychological, and behavioral differences between different age groups may lead to the difference in driving behavior and resulting crashes (Smith et al., 1993; Islam & Mannering, 2006; Lord & Mannering, 2010; Morgan & Mannering, 2011; Shen & Neyens, 2015). Thus, future work should examine whether these results extend to other driver groups (e.g., middle-aged drivers and older drivers). Future work should also evaluate drivers' behaviors during the transitions from higher levels of automation conditions to lower levels of automation conditions when vehicles are at different speeds. The personalities of participants who refused to restart the LK system when it failed, fell asleep during the experiment, and failed to respond to the failure of the LK system when they were watching video clips were removed from the analysis. These personalities need to be investigated further. Future work can develop tools that can identify those drivers from the general population and determine the effects of different levels of automation on their performance when DSS components fail. The current dissertation only investigates the watching video clips as the non-driving task. It will be valuable to explore the effects of other non-driving task (e.g., conversation on cell phone and texting) on drivers' performance when faced with the failure of one of the DSSs. Additionally, it is also important to estimate the mitigated effects of different lane departure warnings in different volumes, tones, and prediction times on drivers' behaviors in fully-autonomous vehicles (i.e., vehicles involve in level 3 automation). Future researches should also evaluate the effects of other warning modalities (e.g., visual, haptic, and the combinations) on drivers' responses to safety critical events in semi- or fully- autonomous vehicles. It will be also valuable to determine if a continuous feedback of automation activities would help drivers remain in the vehicle control-loop and improve their behaviors during safety critical events. Furthermore, future work should explore drivers' interactions with fully-autonomous vehicles and their behaviors in the status transitions from the level 3 automation condition to lower levels of automation conditions (the transition shown by the arrow 5 or 6). It is also very important to evaluate the factors that influence drivers' decisions to engage the autonomous driving systems when they are manually driving the vehicles, that is, the factors that influence drivers' decisions to transition from the levels of automation shown in Figure 17 (a) or Figure 17 (b) to Figure 17 (c).

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APPENDIX I

Demographic survey

Your answers to these questions will remain completely confidential

1. How old are you? ________
2. Are you ☐ Male ☐ Female
3. Do you currently drive a car?

   ☐ Yes ☐ No
4. What is model of your car? ____________
5. What is the year of your car? ______________
6. When was your current drivers license issued? ______
7. Is your car equipped with conventional Cruise Control (only allows drivers to set speed)?

   ☐Yes ☐ No
8. Is your car equipped with Adaptive Cruise Control (ACC)?

   ☐Yes ☐ No
9. Is your car equipped with Lane Keeping?

   ☐Yes ☐ No
10. Have you ever used ACC or LK?

    ☐Yes ☐ No

11. Have you ever heard about the news about the failures of Cruise Control and Lane Keeping?

☐Yes ☐ No

12. How do you rate your driving skills?

☐Excellent ☐Good ☐ Average ☐Fair ☐ Poor

13. How do you think your driving skills compare to others on the road?

☐Excellent ☐Good ☐ Average ☐Fair ☐ Poor

14. On the inter-state freeway, which driving method do you prefer?

☐ Driving with ACC and LK on ☐ Driving manually

15. Who are your usual passengers?

☐ Partner/Spouse ☐ Children ☐ Relatives ☐ Friends ☐ None usually

APPEDIX II

Complacency Potential Rating Scale

Complacency-potential rating scale developed by Singh et al. (1993a). A 5-point Liker-type scale will be used, with response anchors ranging from strongly disagree (1) to strongly agree (5).

Please mark an ‘X’ in the box above the statement that best describes how you feel about that statement.

1. I think that automated devices used in medicine, such as CT scans and ultrasound, provide very reliable medical diagnosis.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

2. Automated devices in medicine save time and money in the diagnosis and treatment of disease.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

3. If I need to have a tumor in my body removed, I would choose to undergo computer-aided surgery using laser technology because it is more reliable and safer than manual surgery.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

4. Automated systems used in modern aircraft, such as the automatic landing system, have made air journeys safer.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

5. ATMs provide a safeguard against the inappropriate use of an individual's bank account by dishonest people.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

6. Automated devices used in aviation and banking have made work easier for both employees and customers.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

7. Even though the automatic cruise control in my car is set at a speed below the speed limit, I worry when I pass a police radar speed trap in case the automatic control is not working properly.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

8. Manually sorting through card catalogues is more reliable than computer-aided searches for finding items in a library.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

9. I would rather purchase an item using a computer than have to deal with a sales representative on the phone because my order is more likely to be correct using the computer.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

10. Bank transactions have become safer with the introduction of computer technology for the transfer of funds.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

11. I feel safer depositing my money at an ATM than with a human teller.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

12. I have to record an important TV program for a class assignment. To ensure that the correct program is recorded, I would use the automatic recording on my DVR rather than manually pressing record.

☐	☐	☐	☐	☐
1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

APPENDIX III

Interpersonal Trust Scale

The interpersonal Trust Scale was developed by Rotter (1967)

1. Hypocrisy is on the increase in our society.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

2. In dealing with strangers one is better off to be cautious until they have provided evidence that they are trustworthy.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

3. This country has a dark future unless we can attract better people into politics.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

4. Fear and social disgrace or punishment rather than conscience prevents most people from breaking the law.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

5. Using the honor system of not having a teacher present during exams would probably result in increased cheating.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

6. Parents usually can be relied on to keep their promises.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

7. The United Nations will never be an effective force in keeping world peace

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

8. The judiciary is a place where we can all get unbiased treatment.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

9. Most people would be horrified if they knew how much news that the public hears and sees is distorted.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

10. It is safe to believe that in spite of what people say most people are primarily interested in their own welfare.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

11. Even though we have reports in newspaper, radio, and T.V., it is hard to get objective accounts of public events.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

12. The future seems very promising.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

13. If we really knew what was going on in international politics, the public would have reason to be more frightened than they now seem to be.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

14. Most elected officials are really sincere in their campaign promises.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

15. Many major national sports contests are fixed in one way or another.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

16. Most experts can be relied upon to tell the truth about the limits of their knowledge.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

17. Most parents can be relied upon to carry out their threats of punishment.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

18. Most people can be counted on to do what they say they will do.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

19. In these competitive times one has to be alert or someone is likely to take advantage of you.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

20. Most idealists are sincere and usually practice what they preach.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

21. Most salesmen are honest in describing their products.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

22. Most students in school would not cheat even if they were sure of getting away with it.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

23. Most repairmen will not overcharge even if they think you are ignorant of their specialty.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

24. A large share of accident claims field against insurance companies are phony.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

25. Most people answer public opinion polls honestly.

☐	☐	☐	☐	☐
1 Strongly Disagree	2 Mildly Disagree	3 Disagree and agree equally	4 Mildly Agree	5 Strongly Agree

APPENDIX IV

Acceptance Scale

A -2 (strongly disagree) to +2 (strongly agree) Likert scale was used to code the response. The Acceptance Scale was modified based on Van Der Laan et al. (1997).

Make judgments of the LK system… (Please mark an “X” in the box below)

1. useful ← ☐ — ☐ — ☐ — ☐ — ☐ → useless
2. pleasant ← ☐ — ☐ — ☐ — ☐ — ☐ → unpleasant
3. bad ← ☐ — ☐ — ☐ — ☐ — ☐ → good
4. nice ← ☐ — ☐ — ☐ — ☐ — ☐ → annoying
5. effective ← ☐ — ☐ — ☐ — ☐ — ☐ → superfluous
6. irritating ← ☐ — ☐ — ☐ — ☐ — ☐ → likeable
7. assisting ← ☐ — ☐ — ☐ — ☐ — ☐ → worthless
8. undesirable ← ☐ — ☐ — ☐ — ☐ — ☐ → desirable
9. Raising alertness ← ☐ — ☐ — ☐ — ☐ — ☐ → sleep-inducing

APPENDIX V

Trust Ratings

The Trust Rating was modified based on Jian et al. (2000).

A 1 (strongly disagree) to 5 (strongly agree) Likert scale was used to code the response

1. I trust lane keeping system

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

2. The performance of the lane keeping system enhanced my driving

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree

3. I prefer to use lane keeping on Interstates or freeways.

1	2	3	4	5
Strongly Disagree	Mildly Disagree	Disagree and agree equally	Mildly Agree	Strongly Agree